

***Acromio-humeral distance; its
measurement reliability, sensitivity and
the influence of scapular position***

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reliability, sensitivity and the influence of
scapular position***

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List of abbreviations

SIAS	Subacromial impingement of the shoulder	AC	Acromion process
AHI	Acromio-humeral interval	SAS	Sub-acromial space
RC	Rotator Cuff	SD	Standard deviation
SIS	Shoulder Impingement Syndrome	SPSS	Statistical Package for Social Sciences
PT	Posterior tilting	IC	Confidence Intervals
UR	Upward Rotation	RS	Root of the spine
ER	External Rotation	TS	Thoracic of spine
SURA	Scapular upward rotation angle	IN	Inferior angle
AHD	Acromiohumeral distance	SUR	Scapular upward rotation
RTUS	Real Time Ultrasound Scanning	dg	Degree
PALM	Palpation Meter	<i>r</i>	Pearson's correlations
US	Ultrasound	DOM	Dominant
MRI	Magnetic resonance imaging	Max	Maximum
AGT	Acromion to greater tuberosity	Min	Minimum
SEM	Standard error of measurement	KT	Kinesiotape
SDD	Smallest detectable difference	NMES	Neuromuscular Electrical Nerve Stimulation
N/A	Not applicable	UT	Upper trapezius
N	Number	SA	Serratus anterior
N/R	Not Reported	EMG	Electromyographical
GT	Greater Tuberosity (GT)	LT	Lower Trapezius
ICC	Intraclass Correlation Coefficient	URA	Upward rotation angle
LSST	Lateral Scapular Slide Test		

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Abstract

The assessment of the acromiohumeral distance (AHD) is an essential part of the clinical shoulder joint examination. Changes of normal AHD occur frequently in individuals with subacromial impingement syndrome (SAIS). Real time ultrasound scanning (RTUS) is a useful imaging technique. It allows for the assessment of distances between the humeral head and scapular landmarks, such as the acromion and the humeral head in several shoulder positions.

This thesis investigates the within-day and between-day reliability of both RTUS in measuring the AHD and the Palpation Meter (PALM) while measuring the scapular position and motion in healthy individuals. Intra-class correlation, standard error of measurement and the smallest detectable difference values were used to determine the intra-tester within-day and intra-tester between-days reliability of both RTUS and PALM devices. A paired t-test was used to determine the differences between the dominant shoulder versus non-dominant shoulder in two positions; neutral and 60 degrees of passive abduction for the AHD by using RTUS and by using the PALM. A paired t-test was used to determine the differences between the dominant shoulder and the non-dominant shoulder at resting position, 60 degrees of passive abduction and full elevation. Both RTUS and PALM were found to be reliable and precise when measuring AHD and scapular position.

Moreover, a correlation analysis was used to determine whether there was a relationship between the AHD and the scapular upward rotation angle (SURA) measurements in 35 healthy volunteers. A moderate correlation between AHD and SURA during 60 degrees of passive abduction was noted.

The case study of five patients who suffered from SAIS was evaluated in comparison to normative data for both AHD measurements by using RTUS and the scapular position measurements by using the PALM to detect the sensitivity of these tools in the presence of pathology. The injured arm demonstrated smaller AHD and SURA during 60 degrees of abduction tasks.

The last phase assessed the effect of modifying the scapular position on the AHD and SURA by using taping, and the effect of the muscle stimulation on AHD. The findings from this intervention programme did show position effects on AHD in healthy individuals, yet its effect should be evaluated in patients who suffered from SAIS.

Chapter one

1. General Introduction

Shoulder pain is considered the third most common musculoskeletal consultation in primary care (Dinnes et al., 2003): the American Academy of Orthopaedic Surgeons (AAOS) reported that in 2006, approximately 7.5 million people went to the doctor's office with shoulder problems (American Academy of Orthopaedic Surgeons, 2009), therefore, shoulder problems present a major social, psychological and economic cost (Bijlsma & Knahr, 2007; Costa et al., 2010).

Shoulder Impingement Syndrome (SIS) has been found to be the most frequent form of shoulder pathology, it is an extremely common problem and a major cause of shoulder pain, accounting for 44-65% of all shoulder complaints made in a visit to a physician's clinic (Michener et al., 2003; Koester et al., 2005). It is also, prevalent in athletes who make an overhead throwing motion as well as in the general population (Hawkins & Kennedy, 1980; Brotzman & Wilk, 2003).

Poor scapular and humeral positions have been reported in subjects who have SIS (Ludewig, & Cook, 2000; Yamaguchi et al., 2000) as both may influence the subacromial space, to what degree is determined by the interplay between the two structures (McKenna, Straker, & Smith, 2009a). There is an agreement among clinicians that abnormal control of the scapular motion may be associated with an increased risk of subacromial compression of the rotator cuff tendons (Karduna, Kerner, & Lazarus, 2005). Alterations in the scapular position and the control afforded by the scapula stabilizing muscles are believed to disrupt the stability and

function of the glenohumeral joint (Weiser et al., 1999). If the synchronous pattern of motion between the scapula and humerus is disrupted the rotator cuff tendons might become impinged under the coracoacromial arch (Fu, Harner, & Klein, 1991). Therefore, it will be necessary in this study to deal with the scapular motion, which appears to be important during glenohumeral elevation.

Many studies (Watson et al., 2005; Bagg, & Forrest, 1988; Lewis et al., 2002; Lewis, Wright, & Green, 2005; Costa et al., 2010) amongst others have used different techniques and tools in measuring the static scapular position, including goniometry, palpation, radiography, photography, tape measurement, Plurimeter-V and the Palpation Meter. However, few of these techniques are used clinically for either cost or practical perspectives (Watson et al., 2005). The PALM has been used to measure scapular medial/lateral displacement and acromion depression and has shown to be reliable tool (Costa et al., 2010). It can also be used to measure scapular upward rotation angle. However, reliability of the PALM to measure SURA has not been tested.

Some studies show that patients with subacromial impingement syndrome have decreased scapular posterior tilting (PT), and upward rotation (UR) (Ludewig et al., 2000; Hébert et al., 2002; Endo et al., 2001; Borstad et al., 2002) compared to healthy subjects, along with increased internal rotation (Endo et al., 2001; Hébert et al., 2002; Ludewig et al., 2000). As a consequence, the anterior aspect of the acromion may travel towards the humeral head during the arm elevation and contribute to reduction of the subacromial space (Ludewig et al., 2000).

Numerous investigators have studied scapular kinematics, with different techniques and methods. However, only a few studies (Solem-Bertoft et al., 1993; Atalar et al.,

2009; Karduna et al., 2005; Thompson, 2010; Silva et al., 2010) have looked at the biomechanical consequences of altered scapular kinematics on the subacromial space, and they have reported that passive alteration in the scapular position may influence subacromial space. In all these studies there is documentation that a change in scapular kinematics may lead to SAIS.

Alterations in the subacromial space appear to be related to SAIS and may be important in the therapeutic treatment and prevention of this disease (Thompson, 2010). Therefore, subacromial space can be considered of a key clinical interest due to its association with the aetiology of SIS when the arm is elevated and its potential impact on function, comfort, and quality of life (MacDermid et al., 2004).

Maintenance of the subacromial space in the shoulder girdle would appear vital for normal shoulder function. The subacromial space can be assessed by measurement of the acromiohumeral distance; this is the distance between the humeral head and the acromion (Luque-Suarez et al., 2013). Therefore, measuring the habitual humeral head position in relation to the acromion may be important when assessing patients with SAIS (McKenna, Straker & Smith, 2009a). To assess the potential for compressive loading on the structure various imaging modalities have been used to gain a greater understanding of the underlying structure relationship, such as shoulder X-ray, but this has problems with error of magnification, patient positioning and identification of landmarks along with the radiation dose patients are exposed to (McKenna, Straker & Smith, 2009a). Magnetic Resonance Imaging (MRI) has been used; the cost and the static nature of it are issues (Birtane, Calis, & Akgun, 2001).

More recently there has been an increasing interest by clinicians in the utilisation of real time ultrasound scanning in rehabilitation for investigating shoulder pathology

due to it having the ability to perform a dynamic examination (Allen & Wilson, 2001). It is suitable to examine tissue both statically and dynamically in an individual, which could predict the outcome of shoulder function in a variety of positions (Duerr, 2010). However, only limited literature is available on the reliability and the validity of RTUS.

Therefore, the aims of this research are to first gain a more thorough understanding of the reliability of RTUS to measure the AHD and the PALM to measure the scapular position and motion in healthy individuals. The test-retest reliability in assessing outcome measures was investigated (chapter four) to ensure changes are a result of the intervention and not due to measurement error.

In reviewing the literature, very little was found on the question of the association between SURA and AHD, but examining these relationships will enhance our understanding of the influence of the scapular motion on mechanisms of SAIS.

The next question in this research was to find the differences in SURA and AHD in patients with SAIS compared to asymptomatic controls. These results will also provide a rationale to select and deliver treatment interventions for patients with SIS. Thereafter, this research hypothesises an intervention protocol focusing on the tape application to investigate the effectiveness of modifying scapular position on the AHD and SURA in healthy individuals. The rationale for using taping is to normalise the scapula-humeral rhythm by altering the scapular muscle activity and correcting the abnormal scapular position.

This research also focuses on the application of Neuromuscular Electrical Nerve Stimulation (NMES) in an attempt to address the effect of muscle contraction on the

AHD. The rational for using NMES is to stimulate the scapular muscle in order to investigate the effectiveness of muscle stimulation on the AHD by using the NMES electronic muscle stimulator.

This chapter has introduced the background for this thesis and given the reasons for the investigations. The significance of SAIS on personal cost in suffering and actual financial costs make this research study important. Figure 1-1 represents the chapters of this thesis and how they are linked together. The chapters unfold the process of the research starting with the literature review - the method overview - the reliability of the studies are discussed in detail also the analysis of the data - the relationship between the SURA and AHD - the comparisons between patients with SAIS and healthy individual without symptoms.

Finally, a chapter on the proposed interventions follows with a discussion of the hypotheses posed in this study showing the success of the aims of the study. The final chapter is a general conclusion of the complete thesis.

The following chapter presents a review of the literature showing how little literature is available with the focus of shoulder injuries.

Chapter 1: General introduction.

Shoulder impingement syndrome affects many individuals, but the underlying causes are far from clear.



Chapter 2: Literature review

The literature would indicate that changes in scapular orientation maybe contributing to the development of subacromial impingement syndrome

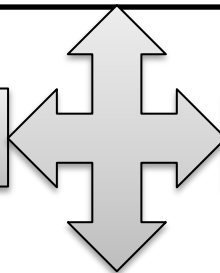


Chapter 3: Method overview

Screening tools which could identify those who exhibited subacromial impingement syndrome (SAIS) is warranted



Chapter 4: Test-retest reliability



4.1 Test-retest reliability of real time ultrasound scanning

4.2 Test-retest reliability of Palpation Meter

Chapter 5: The relationship of scapular rotation to acromiohumeral distance



Chapter 6: Comparison of measures in symptomatic and asymptomatic subjects



Chapter 7: The effect of intervention on acromiohumeral distance and scapular rotation



Chapter 8: General conclusion and future work

Figure 1-1: The chapters of the thesis.

Chapter Two

2. Literature Review

2. 1: What is the subacromial impingement syndrome?

Subacromial impingement of the shoulder (SAIS) is a common musculoskeletal condition believed to contribute to progression of rotator cuff disease (Michener et al., 2003). Neer (1972), who was one of the first to describe the concept of SAIS, defining this disorder as a mechanical compression injury of the tissues of the subacromial space (Neer, 1972). However, it was understood later to be a compression or abrasion of the cuff tendons or tendon of the long head of the biceps brachii beneath any aspect of the coracoacromial arch (Neer 1983).

SAIS can be defined as encroachment of the subacromial soft tissue, especially the tendons of the rotator cuff, underneath the coracoacromial arch as the humerus moves in elevation or abduction, thus decreasing the subacromial space (Neer, 1972; Thompson et al., 2010). In detail, the subacromial space of the shoulder is located between the humerus and acromion which is often referred to acromio-humeral interval (AHI) (Weiner and MacNab, 1970).

The upper border of the space consists of the acromion, coracoid process and the coracoacromial ligament, while the lower border consists of the superior aspect and greater tuberosity of the humerus, within this area there are tissues such as the supraspinatus tendon of the rotator cuff, the biceps tendon and the bursa, (Bigliani and Levine, 1997). These tissues are compressed between the superior humeral head and the inferior acromion, any contact between these structures may result in pathology

and a potential risk for injury as a consequence limiting the subacromial space (Michener et al., 2003).

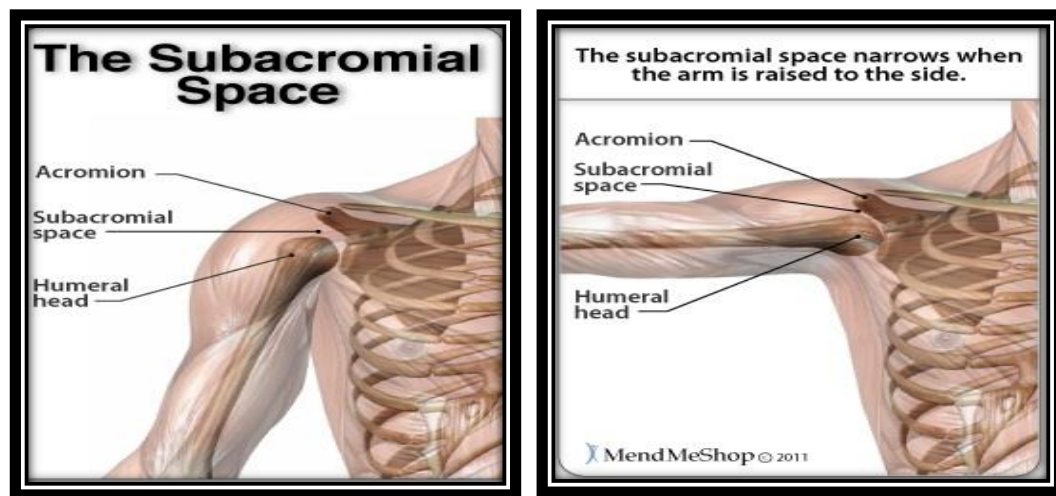


Figure.2-1. Changes in the subacromial space- front view adopted (Mend Me Shop 2011).

Moreover, the SAIS presents itself in many forms, ranging from inflammation to degeneration of the bursa and rotator cuff (RC) tendons of the subacromial space.

2.1.1 Classification of subacromial impingement syndrome (SIAS)

Neer (1983) divided this progressive disorder into three stages.

Stage 1: this stage is typically found in patients of more than 25 years with history of overuse of the overhead arm position, which thus causes inflammation, including oedema in the subacromial bursa and the supraspinatus tendon. Patients who continue use the arm in the overhead position and ignore Stage 1 may progress to Stage 2.

Stage 2: occurs in patients between the ages of 25–40 years old, and is characterised by more thickening of the bursa with fibrosis and damage to the supraspinatus and infraspinatus tendons. Further use of the arm may lead to Stage 3.

Stage 3: is seen in patients above the age of forty and results in tearing or fraying of the supraspinatus and infraspinatus tendons, possible rupture of the long head of the biceps tendon and alterations on the surface of the humeral head (Neer, 1983).

2.2 Incidence and prevalence of subacromial impingement syndrome

Shoulder pain is considered the third most common musculoskeletal condition in primary care (Dinnes et al., 2003). Shoulder Impingement Syndrome (SIS) has been found to be the most frequent form of shoulder pathology and it is an extremely common problem, accounting for 44-65% of all shoulder complaints during a medical clinic (Michener et al., 2003; Koester et al., 2005).

It is estimated that between 7 and 26% of the general population and one-year prevalence of 7-47% of self-reported shoulder pain are affected by shoulder problems. The cost to the individual in reduced quality of life and functional capacity (Luime et al., 2004; Van et al 2010; Bot et al., 2005), is estimated to be around 1-2% annually (Linsell et al., 2006). Among patients in primary care the annual consultation prevalence has been estimated to range from 2-10% of the population (Linsell et al., 2006; Greving et al., 2011; Feleuset al., 2008), and the incidence from 11-30/1000 person-years (Bot et al., 2005; Luime et al., 2004; Greving et al., 2012; Van, Stoel, and Rozing, 1995). The prevalence of SAIS may lead to partial or full thickness tear of the rotator cuff tendons (Michener et al., 2003; Seitz, 2010). Therefore, the consequences of SAIS are functional loss and disability (Michener et al., 2003).

2.3 The cost of shoulder pain

The cost of shoulder complaints to society is a major economic problem. For instance, in the United States, the direct cost for treatment of shoulder dysfunction was estimated to \$7 billion in 2000 (Meislin, Sperling, and Stitik, 2005) and in the European Union the cost of treatment and lost productivity is estimated to 0.5-2% of the gross national product (Luime et al., 2004; Woolf and Akesson, 2001). Musculoskeletal problems in Sweden represent about one third of all sick-leave (Hubertsson et al., 2011; Bergman et al., 2001). In addition there were approximately 3.75 million working days per year lost in the United Kingdom (2008–2009) due to musculoskeletal problems (Tekavec et al., 2012).

One inclusive review of shoulder disorders estimated the cost of shoulder pain to society to be in the region of £100 million (Van et al., 1999), as the prevalence of painful joints increases with age (Badley et al., 1992), these costs are likely to increase in the coming years equivalent with the predicted increase in life expectancy (McKenna et al., 2009).

2.4 The aetiology of shoulder impingement syndrome

The aetiology of SIS is multifactorial; these factors can be described under two main categories, intrinsic and extrinsic mechanisms or a combination of both.

2.4.1. Intrinsic mechanical factors

Partial or full thickness tendon tears occur as a result of the degenerative process with overuse in patients who use overhead motions in their work as well as athletes who participate in throwing sports (Bigliani et al., 1997).

This causes SIS, including inflammation and thickening of the RC tendons or subacromial bursa, thus leading to friction of the subacromial structures against the coracoacromial arch (Bigliani et al., 1991; Bureau et al., 2006; Iannotti et al., 1991), this inflammatory process is thought to result in tendon degradation due to the natural process of aging (Iannotti et al., 1991; Milgrom et al., 1995; Tempelhof et al., 1999). Consequently, tendon degeneration and tears are believed to cause muscle changes, such as imbalances and weakness, and altered shoulder kinematics, which eventually lead to the shoulder impingement syndrome (SIS) (Bigliani et al., 1997).

2.4.2 Extrinsic mechanical factors

This is defined as a compression of the RC tendons and associated tissues within the subacromial space under the anterior aspect of the acromion, in the bursal side of the RC tendon. This is due to narrowing of the subacromial space including anatomical or biomechanical factors or a combination of both, this condition is called the subacromial impingement syndrome (Neer 1983, 1972).

2.4.2.1 Anatomical factors of shoulder impingement syndrome

The anatomical characteristics of the subacromial space contain a number of soft-tissue structures: the coracoacromial arch is the superior border of the space, which consists of the acromion, the coracoacromial ligament and the coracoid process. The inferior border consists of the greater tuberosity of the humerus and the superior aspect of the humeral head. Finally, the acromioclavicular joint is directly superior and posterior to the coracoacromial ligament. Any abnormality that disturbs these anatomical characteristics may cause impingement (Bigliani, et al., 1997).

One of the most important factors related to rotator cuff pathology is acromion morphology; the most widely used classification system for the acromial shape classifies this into type I (flat), type II (curved), or type III (hooked). Another possible factor is that the tendons or bursa of the subacromial space include a degree of inflammation (Fu et al., 1991; Bigliani et al., 1997; Ogata et al., 1990).

This inflammation could hypothetically lead to a decrease in the size of the subacromial space involving increased compression of the tissues against the border of the subacromial space (Bigliani et al., 1991). An additional factor is the relationship between posture and the upper extremities. Wiker et al., (1990) claim that overhead working can be a strong contributor to upper extremity muscle fatigue as a result of abnormal postures which may cause pain or discomfort and subacromial impingement (Steven et al., 1989).

2.4.2.2 Biomechanics of shoulder impingement syndrome

Several factors have been proposed as contributing to the development of SAIS, including postural abnormalities, rotator cuff and scapular muscle performance deficits and decreased extensibility of the pectoralis minor or posterior shoulder tissues, as well as scapular and humeral kinematic abnormalities that can cause dynamic narrowing of the subacromial space (Bigliani et al., 1997). There is evidence to suggest that scapular positioning is abnormal in patients with musculoskeletal disorders such as SIS (Ludewig et al., 2000; Hébert et al., 2002; Cools et al., 2003). SIS leads to extrinsic mechanical rotator cuff tendon compression: this includes abnormal humeral and scapular kinematics, which can cause dynamic narrowing of the subacromial space, leading to Rotator Cuff (RC) tendon compression (Seitz et al., 2011).

Evidence for changes in scapular orientation following fatigue has been inconclusive in the literature; some studies show that patients with SAIS have decreased scapular posterior tilting (PT), and upward rotation (UR) (Ludewig et al., 2000; Hébert et al., 2002; Endo et al., 2001; Borstad et al., 2002) compared to healthy subjects, along with increased internal rotation (Endo et al., 2001; Hébert et al., 2002; Ludewig et al., 2000). As a consequence, the anterior aspect of the acromion may travel towards the humeral head during the arm elevation and contribute to reduction of the subacromial space (Ludewig et al., 2000).

However, other studies (Lukasiewicz et al., 1999; Su et al., 2004; Lin et al., 2005) have demonstrated no differences in scapular UR in subjects with SIS in contrast with a control group. A study by McClure et al, (2006) demonstrated an increase in scapular upward rotation in patients with SIS compared to healthy subjects (McClure et al, 2006).

In the systematic review by Timmons et al. (2012), the authors identified sixty-four published papers; three additional papers were identified by examining the references. Two reviewers reviewed abstracts to determine whether the papers compared subjects with SIS with those without SIS and whether they presented scapular-kinematic variables, and whether they were review articles (Timmons et al., 2012). Table 2.1 summarise the scapular kinematics in subjects with SIS compared to the healthy control.

Table. 2.1: The scapular kinematics and subacromial space: A systematic review in subjects with shoulder impingement syndrome compared to healthy control.

Study	Measurement	Subjects	Method	Results
<i>Lukasiewicz et al 1999 [36]</i>	Static scapula position Orientation at 0°, 90°, maximal arm abduction in the plane of the scapula	N =20 controls 17 subacromial impingement between (25 and 66)years both genders	3D Electromagnetic	<p>There were no differences between-groups for scapular UR at all three test positions</p> <p>The sis group had less PT at the 90° and maximal positions than the control group</p> <p>There were no differences between-groups for ER for all three test positions of 0°, 90°, and maximum arm elevation in the scapular plane.</p> <p>Subjects with sis showed less PT and greater superior scapular position in the 90° and maximum arm-elevation positions in the scapular plane than those without SIS.</p>
<i>Ludewig and Cook 2000 [30]</i>	Scapular position Orientation during dynamic scapular-plane elevation at three arm elevation angles 60°, 90°, and 120°	N=26 controls, 26 SIS shoulder impingement (20-71) years only male (overhead construction workers)	3D Electromagnetic	<p>Scapular UR: Subjects with sis had less UR at 60° arm elevation than controls, There were no differences at 90° or 120° elevation.</p> <p>Scapular PT: Subjects with SIS had less PT at 120° than controls</p> <p>Scapular ER: Subjects with SIS had less ER. Subjects with SIS showed less scapular PT, less ER, and less UR than subjects without SIS did</p>
<i>Borstad and Ludewig 2002 [35]</i>	Scapular orientation at 40°, 60°, 80°, 100°, and 120° during elevation in the scapular plane	N=26 controls, 26 with shoulder impingement SIS	3D Electromagnetic	<p>Subjects with SIS had significantly less scapular UR at 40° and 60° arm elevation and significant</p> <p>Decrease in PT at 100° and 120° of arm elevation during both control and patient group</p> <p>Subjects with SIS had significantly more scapular internal rotation at 120° arm</p> <p>Small differences in scapular PT and ER between both control and patient group occurred at arm-elevation angles greater than 80° in subjects with and without SIS.</p>

Hebert et al 2002 [31]	Scapular orientation during static arm positions at 70°, 90°, and 110° arm elevation in the sagittal and frontal planes	N= 39 control, 41 with shoulder impingement syndrome (SIS)	3D Electromagnetic	<p>During elevation in the sagittal plane, subjects with SIS had less UR and ER while having more PT than controls.</p> <p>During arm elevation in the frontal plane subjects with SIS had less UR, ER, and PT than controls. - The contribution of rotations and scapular total range of motion differed according to the plane of arm elevation in the SIS group.</p> <p>Group analyses revealed no differences in 3D scapular attitudes between symptomatic and asymptomatic shoulders of subjects with unilateral SIS.</p>
Endo et al 2001[34]	Static comparisons	N=27 with unilateral impingement, (41-73) years, both genders	Radiographs	<p>There were no significant differences found between the groups.</p> <p>Healthy group having more UR at 45°, 90°, and 135° arm elevation.</p>
Mcclure et al 2006[40]	Scapular upward rotation during posterior tilt internal rotation elevation retraction	N= 45 controls, 45 with impingement (24-74) years both genders	Goniometry Electromagnetic	<p>Group with shoulder impingement</p> <p>Increase scapular up ward rotation</p> <p>Increase posterior tilt</p> <p>No significant different found in internal rotation</p> <p>Increase in both elevation and retraction.</p>
Graichen et al 2001[39]	Scapular orientation at 30°, 90°, and 120° of arm abduction	N=14 controls and 20 with shoulder pathology (14 SAIS, 6 RCT) (22-62) years genders	MRI 3D	<p>No significant difference in UR, PT, or ER was found between the groups.</p> <p>Five subjects with sis showed a significant increase in glenoid rotation. Subjects with sis showed no differences in scapular motion from subjects without SIS.</p>

In general, there is an inconsistency in the reported scapular-kinematic alterations in patients with SIS. Substantially, eight out of fourteen cited studies identified a significant group difference in at least one variable. Therefore, further investigation is essential to determine which scapular kinematic alterations are most related to changes in subacromial space and what magnitude of change in scapular kinematics is required to affect the subacromial space.

2.4.2.2.1 Scapular kinematics

Several factors have been proposed as contributing to the development of SAIS. One of these factors is altered shoulder kinematics associated with dysfunction of the scapula (Kibler, 2006). Scapular movement is an essential component in arm elevation. The scapula is involved anatomically and biomechanically in proper shoulder function relating to overhead activity (Kibler & McMullen, 2003). First: the scapula keeps an optimal muscle length for maximum strength output throughout a large range of motion (Hart & Carmichael, 1985; Kibler, 1998). Second: during humeral elevation, the scapula separates the subacromial space from the rotator cuff, thus reducing impingement and coracoacromial arch compression (Ludewig, & Cook, 2000; Lukasiewicz et al., 1999; Kibler, 1998). The final and the most important role of the scapula in shoulder function is its performance as a link between proximal and distal parts of the body in order to transfer large forces and high energy from the legs, back and trunk to delivery points, such as the arm and the hand and humerus for overhead movements (Kibler, 1995; Kennedy, 1993; Kibler, 1998).

The anatomical and movement analysis perspective concluded that the muscular system is the main contributor to scapular positioning at rest as well as during functional tasks. Altered muscle activity is likely to cause abnormal scapular position: thus, inappropriate control of scapular positioning has frequently been linked to the development of SIS (Hébert et al., 2002).

Alterations in scapular kinematics and muscle activity have been reported in patients with SIS and rotator cuff disease (Ludewig & Cook, 2000). Previous studies have indicated that any abnormalities in the scapular position may influence the subacromial space, (Atalar et al., 2009; Solem-Bertoft et al., 1993). For instance, a

study by Atalar et al. (2009) showed that limiting scapular motion by externally binding the scapula down to the thorax while the arm is positioned at 90 degrees causes a decrease in subacromial space compared to the situation with an unrestricted scapula. Another study by Solem-Bertoft et al. (1993) has demonstrated that in 4 healthy individuals positioning the scapula in protraction compared to retraction with sandbags reduced the subacromial space. However, a study by Karduna et al. (2005) on cadavers found that inducing scapular upward rotation from a neutral position reduced subacromial clearance (Karduna et al., 2005).

The particular interest to this study is the relative contributions of the upper and lower serratus anterior muscles and trapezius muscles, which are found to stabilize the scapula and induce scapular upward rotation, external rotation and/or posterior tilt. Altered function of these two muscles has been found to influence the scapular movement, and is associated with subsequently poor shoulder function and chronic impingement problems (Michener et al., 2003). These components of scapular movement are important for widening the subacromial space to prevent the impingement of the subacromial tissues during elevation (Michener et al., 2003; Solem-Bertoft et al., 1993).

Overall, the serial muscle activation patterns stabilise the scapula and increase control over its movement and position as the arm is moved. Therefore, it is very important to have a good system of scapula muscle activation to obtain optimum function (Kibler & McMullen, 2003).

2.5 Clinical evaluation

Normally, patients with SAIS have pain during everyday activities such as combing one's hair or reaching up into a cupboard. Patients usually complain of pain at night, which becomes worse when lying on the affected shoulder or sleeping. This pain is usually localised into the antero-lateral acromion and often radiates to the lateral mid-humerus when the arm is overhead (Kibler, 1998).

2.5.1 Physical examination

A study by Papadonikolakis et al. concluded that the Neer sign (pain on forced flexion), and the Hawkins sign (pain on internal rotation with the arm elevated to 90°), can be used to diagnose the impingement syndrome (Papadonikolakis et al., 2011).

2.5.1.1 Impingement tests

The impingement test is considered as a first step in clinical testing (Table 2.2).

Neer, (1983) and Hawkins, et al (1980) have proposed these impingement tests to reproduce symptoms or pain by compressing the greater tuberosity against the acromion.

Table 2.2: Clinical tests for impingement	
Shoulder pathology	Clinical tests for the pathology
Subacromial impingement syndrome	Neer Sign
	Hawkins-Kennedy Test

2.5.1.1.1 Neer impingement test

The patient is seated while the examiner stands; the examiner passively elevates the patient's shoulder to the position of maximal elevation on one hand, while stabilizing the scapula on the other hand (Fig.2-2).



Figure.2-2 Neer Impingement test adopted (Anna 2011)

2.5.1.1.2 Hawkins and Kennedy impingement test:

The humerus forward flexion to 90° combined with maximal internal rotation of the shoulder (Fig.2.3).



Figure.2.3. Hawkins and Kennedy Impingement test adopted (shoulderdoc. n.d.)

This chapter has discussed in detail the actions involving the shoulder joint and the many variations of movements which cause pain. The chapter gives many diagrams of the movements of the shoulder joint and demonstrates how and why pain is caused. The relevant literature has been explored and discussed with a view to the author of this study being able to offer some therapeutic solutions for SAIS and the accompanying problems. The next chapter will describe the method overview of this study.

Chapter Three

3. Methods including review of the relevant literature for each tool

3.1 Method overview

This chapter gives a detailed discussion of the tools used for measuring the AHD and the scapular position and rotation. It is important that all the modern equipment is evaluated and this chapter assesses in detail the tools used. A description of the method used for this research and the reasons for choosing this methodology is presented.

The articles in the literature review displayed a variety of objectives and research designs. Various methods were used to measure the distance between the humeral head and acromion evaluating the AHD and to assess the scapular position and SURA including RTUS and PALM. Therefore, this chapter will provide an overview of how various screening tools can be used for assessment of AHD and SURA.

First: the RTUS methods and the distance measurement values in different populations, together with the reliability of this method.

Second: the PALM methods and the distance measurement values in different populations, together with the reliability of this method.

3.1.1 Ultrasound imaging examination

Ultrasound (US) is a sound wave with a frequency greater than 20,000 cycles per second (Duerr, 2010). The frequencies for RTUS range between 3.5 and 15 MHz (Whittaker, et al 2007). More recently, there has been an increasing interest from clinicians in the utilisation of RTUS in rehabilitation and investigating shoulder pathology, as it enables dynamic examination, but it has been mainly applied in distinguishing between normal and pathological anatomical structures (Lew et al., 2007). It is suitable to examine tissue both statically and dynamically, and could be used to predict the outcome of shoulder function in a variety of positions (Duerr, 2010). Diagnostic US, in contrast to other common imaging techniques, is considered inexpensive and portable, it shows very little associated risk and does not emit radiation, it is non-invasive and it is highly acceptable to patients (Awerbuch, 2008, Gilbert, 2007). In particular, the visualisation of movement in real-time and the option of interaction with the patient during examination are considered major advantages of US (Whittaker et al., 2007).

Standard RTUS including the AHD outlet views are important for full evaluation of shoulder pain. The simple RTUS may show characteristic changes of the shoulder disorder, including SAIS through narrowing of the AHD (Weiner and Macnab, 1970; House & Mooradian, 2010). Magnetic resonance imaging (MRI) is typically performed with the arm adducted or by the side; however, these positions do not recreate the position of impingement (Harrison & Flatow, 2011). Therefore, the aim of this literature review was to identify articles that used RTUS to quantify distances between the humeral head and the acromion, in order to establish the influence and effect of rehabilitation on AHD, the search was conducted in the most popular electronic data bases.

3.1.2 Ultrasound overview of selected articles

Search strategy processes were carried out thorough search of the literature using the electronic databases Scopus (including 100% of MEDLINE); the PubMed NCBI database; Sports Discus; Google Scholar; Furthermore, for further eligible articles the reference lists of all recovered articles were searched. The articles to be included in the review should provide information on RTUS reliability and AHD measurements and changes in distances between the humeral head and acromion. Studies that did not discuss these factors and were not published in English were excluded.

On reviewing the literature the search identified articles involving the use of RTUS in measuring the subacromial space and the AHD and the reliability and the usefulness of RTUS for diagnosis and evaluation of the AHD. A total of 45 citations of which 820 non-relevant titles or duplicates were removed in the initial screening, the researcher then assessed the remaining 45 articles by the title and the abstract. These were narrowed down to 20 based on describing the reliability of US to measure the distance between the head of the humeral and the acromion in the superior-inferior direction, the position of the transducer on the shoulder in the side view (see figure 3.1).

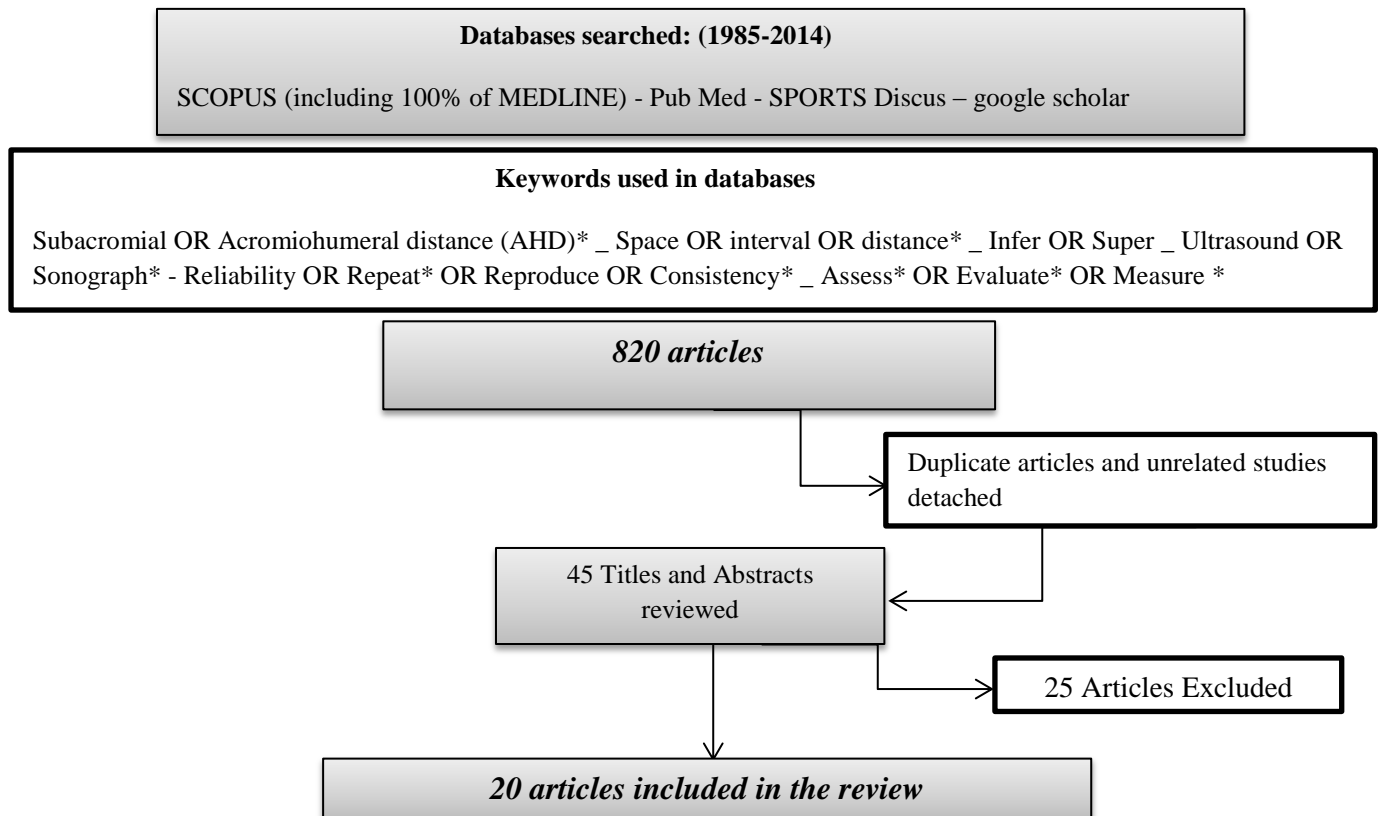


Figure 3.1 Search strategies for Ultrasound selected articles.

Twenty authors evaluated the reliability for RTUS used for measuring the width of the subacromial space and the AHD. 16 studies (Luque-Suarez et al., 2013; Maenhout et al., 2013; Leong et al., 2010; White et al., 2012; Kumar et al., 2011; Kalra 2010; Kumar et al., 2010; Duerr, 2010; Pijls et al., 2010; Seitz, 2010; Silva et al., 2008; Cheng et al., 2008; Girometti et al., 2006; Fremont et al., 2000; Michener et al., 2013; Bdaiwi et al., 2014), were found to have reported intra-rater reliability, while eight articles (Wang et al., 2005; Desmeules et al., 2004; Azzoni et al., 2004; Fremont et al., 2000; Pijls et al., 2010; Kumar et al., 2011; Cheng et al., 2008; Bdaiwi et al., 2014), evaluated inter-tester reliability and five studies (Cheng et al., 2008; Kumar et al., 2010; Pijls et al., 2010; Kumar et al., 2010; Duerr, 2010 ; Bdaiwi et al., 2014) investigated both types of reliability. The majority of studies (Luque-Suarez et al., 2013; Maenhout et al., 2013; White et al., 2012; Kalra et al., 2010; Pijls et al.,

2010; Seitz, 2010; Silva et al., 2008; Cheng et al., 2008; Girometti et al., 2006; Fremont et al., 2000; Desmeules et al., 2004; Azzoni et al., 2004; Bdaiwi et al., 2014; Michener et al., 2013) determined the AHD in the sagittal or scapular plane by measuring the shortest distance between the bony landmarks of the acromion and the humeral head, while the remaining authors (Kumar et al., 2010; Kumar et al., 2011; Leong et al., 2010; Cholewinski et al., 2008) measured the acromion to the greater tuberosity distance (AGT) which anatomically is a longer distance, three studies established the reliability only for the neutral arm position.

In the study by (Duerr, 2010), the author evaluated both the intra and inters tester reliability of the two distances AGT and AHD, and compared the intra-rater reliability of measuring the two distances. The result indicated that the greater tuberosity could not be visualised on ultrasound images in abduction. As a consequence, this may limit the clinical usefulness of measuring the AGT in abduction. The remaining two articles namely, Silva et al., 2008 and Cholewinski et al., 2008 did not provide any information about the reliability measurement and the patient landmarks and position were insufficiently described. In addition, Wang et al., (2005) study assessed the reliability from pilot data, there was no information on the number of subjects and the landmark is not described in detail.

Moreover, previous studies demonstrated a reduction in the reliability of measurements taken by several examiners (inter-rater reliability) in contrast to one examiner (intra-rater reliability) (Cheng et al., 2008; Fremont et al., 2000; Pijls et al., 2010; Kumar et al., 2010). Interestingly, Cheng et al. (2008) and Pijls et al. (2010) reported comparably high reliability between an experienced RTUS examiner and a novice. Correspondingly, Fremont et al. (2000) found reliability levels for two

physiotherapists taking RTUS measurements that are comparable to the reliability of two experienced radiologists in the study of Desmeules et al. (2004).

Regarding the methodology of reliability analysis, all studies scan the AHD in the neutral shoulder position, while different studies were carried out additional images in various positions (30°, 45°, 60° and 90°) either active or passive abduction and all these studies used a high frequency linear transducer (between 5 and 12.5 MHz) to obtain the ultrasound scans. There was difference in placing the transducer, some of the studies placing the transducer on the anterior part of the acromion, (Desmeules et al., 2004; Pijls et al., 2010) whereas others used the posterior or mid-acromion (Kalra et al., 2010) or did not provide sufficient information about the testing protocol.

Likewise, most of these researchers have provided an Ethical approval and consent form. However, the studies obtained by Girometti et al., 2006; Fremont et al., 2000; Desmeules et al., 2004; Azzoni et al., 2004 did not provide any information on either Ethical approval or signing the consent form. According to Bowling, (2002) Ethical approval and informed consent must be gained prior conducting the research. The importance of consent is to respect patient autonomy and prevent harm (Polgar and Thomas, 2013). Furthermore, there were considerable differences in; the number of scans, sample size, and participants' characteristics (Table. 3.1). The participant sample size was low in some studies (Leong et al., 2012; White et al., 2012; Girometti et al., 2006; Desmeules et al., 2004; Fremont et al., 2000). Determining the optimal sample size for a study assures adequate power of the study to detect statistical significance. Hence, it is a fundamental step in the design of a planned research protocol (Suresh and Chandrashekara, 2012); this is why the power calculation should be made to justify how many participants should be included.

All researchers used appropriate statistical tests that correlated with their studies. However, the testing of these statistical procedures had potential limitations due to the reporting of the statistical results. These statistical results were not detailed enough. Most of these studies failed to report the SE of measurement (SEM) values as well as the smallest detectable difference (SDD); the SEM values for AHD was reported in 11 studies (Luque-Suarez et al., 2013; Maenhout et al., 2013; Leong et al., 2012; Kumar et al., 2011; Kalra et al., 2010; Kumar et al., 2010; Duerr, 2010; Cheng et al., 2008; Girometti et al., 2006; Michener et al., 2013; Bdaiwi et al., 2014) and were below 1 mm. While, only five studies (Kalra et al., 2010; Leong et al., 2012; Michener et al., 2013; Bdaiwi et al., 2014) reported the SDD which is an important measure, representing the amount of change required to exceed measurement variability (McCreesh et al., 2013), and it is an important factor which determines future research and clinical decision making. The reported SDD measurement in the neutral shoulder position for acromion to greater tuberosity distance were 1.3 mm (Kalra et al., 2010), 2.1 mm (Leong et al., 2012), 0.9 mm (Duerr, 2010) and for AHD were 0.9 mm Duerr, (2010), 0.8mm (Michener et al., 2013) and 2.2 mm (Bdaiwi et al., 2014) and both Duerr, (2010) and (Bdaiwi et al., 2014) have reported the SDD at 60 degrees of abduction position for acromial humeral distance of either passive or active abduction. Table .3.1 Provides a summary of the reliability values for the real time ultrasound scanning (RTUS) for the measurement of the distance between the head of the humeral and acromial.

Table. 3.1: Reliability values for the real time ultrasound scanning (RTUS) for the measurement of the distance between the head of the humeral and acromion.

Authors titles	Subjects numbers examiners	Shoulder position	Distance measure & Transducer location scan number	Intra-rater ICC	SEM (mm or cm)	SDD (mm or cm)	Inter-rater ICC	SEM (mm or cm)	SDD (mm or cm)	Methodological issue
Luque-Suarez et al (2013)	Healthy participants N= 49 subjects	0° 60° Active	AHD-Along the major axis of the humerus and parallel to the flat superior aspect of the acromion 5-12 MHz linear transducer.	0.94 0.87	0.21mm	-	N/A			(-): 1. time interval of 2 min between each measurement 2- SDD not reported 3- inter test reliability not assessed (+): 1. randomised controlled trail.
Maenhout et al (2013)	N=62 female overhead athletes 29 elite handball players 33 different sports	0° 45° 60° Active	AHD-The coronal plane, parallel with parallel with the long axis of the humerus 5- to 10-MHz linear transducer	0.92 0.88 0.91	0.54mm 0.87mm 0.75mm	- - -	N/A N/A N/A			(-): 1. inter test reliability not assessed and the SDD not reported (+): 1. Scanning started at random on the dominant or non- dominant side. 2.The positions standardized and corrected before the start of ultrasound scanning
Leong et al (2012)	N=37 individuals 24 volleyball players 9 with SAS & 15 healthy 13 healthy individual 2 –sessions with 7-10 days part one sports physiotherapist	0°	AGT The lateral surface of the shoulder the infero-lateral edge of acromion to the apex of the greater tubercle- 3measures 8–12 MHz linear transducer	0.93	0.75 mm	2.10 mm	N/A			(-): 1. small number of participants in each group affected the power 2- ICC,SEM-SDD for 60 degrees of abduction not reported 3- Other factors that may influence AGT such as laxity and shoulder flexibility not tested (+): 1. Ultrasound measurement of acromio- humeral distance could identify players at risk in having SIS

White et al (2012)	Healthy participants N=58 (40 women, 18 men) 10 subjects were selected for the reliability one investigators	0 ° 30° 45°	AHD-The inferior surface of the anterolateral acromion to the top of the humerus three images for each position 7.5-12 MHz linear transducer Two separate occasions	First day: 0.86 All conditions: (0.98 - 0.99) N/R N/R	after 3-4 day: 0.94 N/A N/A	(-): 1. small number of subjects for the reliability 2- reliability was established just for the neutral arm position 3- asymptomatic young subjects (+): 1. validity measurements of AHD with no muscle contraction using US of similar studies that measured AHD using magnetic resonance imaging, ultrasound, & radiography.
Kumar et al (2011)	Healthy participants N= 20 subjects Three raters Physiotherapy students	0°	AGT-distance between the lateral tip of the acromion process (AC) and the nearest margin of superior part of the greater tuberosity (GT) 6 - Measurement recorder for each subject - Three measurements 10-5MHz linear transducer	Rater1: 0.88 (0.15 cm) Rater2: 0.84 (0.12 cm) Rater3: 0.91 (0.11 cm)	Session: 0.79 (0.15cm) N/R	(-): 1. small convenient sample with a relatively young age 2. lack of randomisation, 3. Between days measurements were reported for individual participants. (+): 1. provide the clinical usefulness of (AGT) distance that could potentially be used diagnoses of SIS & subluxation in Stork
Kalra et al (2010)	Two different groups N= 60 subjects N = 31 control subjects Shoulder pain, N = 29 one investigator	0 ° 45°	AHD -The transducer placed over the posterior to middle portion of the Acromion in the coronal plane. 7.5-MHz linear transducer 2- ultrasound images recorded	One rater: 0.92 (0.9 mm) (1.3 mm) 0.76 (0.6 mm) (2.2 mm)	N/A	(-): 1. The study fail to address any intervention for posture correction therefore, the result cannot be applied the effect of posture treatment (+): 1. measuring SAS elevation angles greater than 35° to 40° may be not important due to the supraspinatus tendon being found to be at greatest risk of impingement at elevation angles of 28° to 36° between the acromion and the greater Tuberosity

Kumar et al (2010)	Healthy participants N= 32 subjects' physiotherapist	0 °	AGT-distance between the lateral tip of the acromion process (AC) and he nearest margin of superior part of the greater tuberosity (GT) 10-5MHz linear transducer 2 weeks part between session 2- measurements recorded	One rater: 0.98 (0.06 cm)	Session: 0.97 (0.07cm) N/R	(-): 1. interrater reliability was not assessed and the SDD not reported 2.intrarater within and day to day reliability established for the neutral arm position only (+): 1. intrarater within and day to day ultrasonographic measurement of AGT very reliable in healthy individuals.
Duerr (2010)	Healthy participants N= 40 subjects N= 19 overhead sport activities same examiner	0 ° 0 ° 60 ° Active 60 ° Passive	AGT- the distance between the acromion and the edge of the greater tuberosity AHD- the external inferior edge of the acromion and at the most superior aspect of the surface of the humeral head 2- measurements were recorder 12-5 MHz linear- transducer and a 9-4 MHz curved-transducer (Session 1 and Session 2), four and seven days apart	Session 1: 0.92 (0.03) (0.09 cm) Session 2: 0.88 (0.04) (0.12 cm) Session 1: 0.87 (0.03) (0.09 cm) Session 2: 0.97 (0.01) (0.03cm) Session 1: 0.94 (0.02) (0.04 cm) Session 2: 0.94 (0.02) (0.02 cm) Session 1: 0.96 (0.01) (0.03 cm) Session 2: 0.98 (0.01) (0.05 cm)	Between session 0.80 N/R Between session 0.89 Between session 0.82 Between session 0.83	(-): 1.the inter-rater reliability not investigated 2. SEM & SDD between sessions not stated 3.The measurement not applied in different population (+): 1.superior USI methods used are reliable for the repeated application by a single examiner 2.Small real difference indicates the USI method displays high reproducibility
Pijls et al. (2010)	Patients with SIS N = 43, (50 shoulders) 2 groups: Group 1 - neutral N = 21(24 shoulders) Group 2 -60° abduction N = 22 (25 shoulders) 2 raters Rater 1: Experienced operator; Rater 2: Novice	0° 60°	AHD-measured as shortest distance between acromion and most superior aspect of humerus - 3 measurements 5- to 12-MHz linear array centre frequency of 7.5MHz	Experience: 0.94 - - Novice: 0.92 - - Experience: 0.90 N/R Novice: 0.87 -	Interobserver: 0.70 accuracy 1.1 mm Interobserver: 0.64	(-) 1. the transducer was moved until the smallest AHD was found 2.No information provided if the transducer removed from skin or not between measures 3. Active or passive not reported (+) 1. examiners blinded to own and each other's measurement 2.The position of the arm standardised and controlled well

Seitz et al (2010)	Forty-two subjects N=21 with SAIS N= 21 controls not reported	0° 45° 90° Active a	AHD the shortest linear distance between the humeral head and the anterior inferior tip of the acromion 4-12MHz linear transducer set at a frequency of 8.0 MHz	0.98 - 0.6 mm 0.96 - 0.9 mm 0.95 - 0.8 mm	N/A			(-): 1.inter tester reliability and SEM not reported (+): 1.the examiner blinded arm angle 2. The result powered 3. The SDD reported
Silva et al (2008)	N= 53, Elite junior tennis athletes N=20 Non-athlete control single radiologist	0° 60°	AHD - Measured as the smallest distance between acromion and Humerus 7-12 MHz linear transducer.	N/R	N/A			(-): 1. active or passive abduction and the plane not reported 2. Patient Landmarks and position insufficiently described.
Cheng et al (2008)	Healthy population N =19, normal shoulders 2-rater 1: senior radiology rater 2: non radiologist	0° neutral rotation	Superior surface of coracoid process and most cranial point on antero-superior surface	Observer 1: 0.94 0.6mm Observer 2: 0.84 0.7mm	Inter-observer : 0.85 0.85mm			(-): 1.Transducer placement not described in detail. 2.No information provided how the examiners blinding of their data. 3.SDD not reported
Girometti et al (2006)	Participants N = 10 basketball player N= 10 Non-athlete controls	0°	AHD Lateral to acromial shadow from tendon entry point perpendicular to humeral head / Bilateral scans 5-12 MHz linear transducer.	Rater 1: 0.94 (0.6 mm) Rater 2: 0.89 (0.7 mm)	N/R	N/A	-	(-): 1- the subject number low 2-The placement of the transducer not described in detail 3- SDD and inter rater reliability not reported 4- no data were recorded on reliability for revision of hard copy images by the radiologist. 5. no information on either Ethical approval or consent form

Wang et al (2005)	Elite baseball athletes 3-groups	0°	N/R	N/A	(0.91 - 0.88)	-	-	(-):1. reliability assessed from pilot data 2.the superior landmark is not described in detail 3The arm support in abduction is not standardised (this might provoke muscle contraction) 4. no data of subjects number 5- SEM &SDD not reported (+): Similar accuracy between examiners (similar SEM within sessions).
	Baseball athletes	90°			(0.81 -0.75)	-	-	
	with & without injuries Control group Number of examiners not reported	Passive abduction. Front & scapular plane	5-10 MHz linear transducer					
Desmeules et al (2004)	Population N= 13 subjects N= 7patient with SAS 2 radiologists	(0°) 45° 60° Active	AHD - lateral surface of shoulder, along the longitudinal axis of humerus. At most anterior part of acromial arch and 1 cm posterior to this point 12.5-MHz linear transducer 2 measures	N/A	Between rater: 0.88 0.91 0.92	-		(-):1. underpowered result 2.SEM &SDD not reported 3.no information on either Ethical approval or consent form (+):1.the examiners blinded to the. patient's pathologic shoulder. 2.The order of evaluation by radiologist was randomly allocated for each subject
Azzoni et al (2004)	Pathologic population Patients with shoulder pain, n = 200 divided into four groups 2/examiner		AHD- Most inferior echoic from external, inferior edge of acromion to the nearest point of echo on humeral head 7.5 MHz linear transducer / 3- scan	N/A	-	Session: 0.80	-	(-):1. Reference point for the transducer placement described not enough 2.the reliability assessed from the correlation coefficient not from ICC 3.Mean values and SEM not reported
Cholewinski et al (2008)	N = 57, Patients with SIS N= 72, control		AGT -Inferior-lateral edge of acromion to the apex of greater tuberosity. scans. - 8-MHz linear transducer 6-MHz linear transducer was used for patients 3 measures	N/R				(-): 1.the placement of the transducer insufficiently described 2. No information on the reliability and the authors only provide the median

Fremont et al (2000)	Healthy subjects N= 10 (20 shoulders). 2 /non radiologists	0 °	AHD- Lateral tip of the acromion to the humeral head Surface 6-10 MHz linear transducer (set at 8 MHz)	Rater 1:0.69 0.81		N/R	Session 1: 0.78 0.90		N/R	(-):1. Small subject number 2.high reliability achieved in active abduction higher than in neutral 3.the results just published in abstract format 4. the number of subjects not taken into account. 5.no information on either Ethical approval or consent form
		45°		Rater 2: 0.81 0.92			Session 2: 0.79 0.86			
		0 ° 45° Active	2 scan – 2sessio (5-7 days apart)							
Michener et al 2013	40 subjects N= 20 with SAIS N= 20 control single examiner physical therapist	0 °	AHD The most anterior aspect of the anterior acromial margin, and parallel to the flat surface of the acromion 4–12-MHz linear transducer set at 8 MHz 3- measures /	0.98	N/R	0.8mm			N/A	(-):1.not evaluate the change in measures with treatment or over time 2.images may not have captured the most inferior aspect of the acromio (+):1 the result powered 2. excellent reliability& the SDD was reported
Bdaiwi et al 2014	healthy individuals N=20 subjects single examiner	0 ° 60 ° Passive	AHD- the lateral edge of the acromion process of the scapula to the nearest margin of the humerus 7–13-MHz image set at 13 MHz 3- Measure	0.83 0.83	0.78 0.19	2.1mm 1.7mm	0.72 0.74	0.82 0.78	2.3mm 2.2mm	(-):1. inter-tester reliability was assessed from analyse the images 2. the order of the position not was randomise (+):1. investigators were blinded to each other 2.the result powered 3. both SEM & SDD were reported

3.1.3Conclusions

Overall, it has been shown in all studies using AHD measurements that when taken with a superior-inferior USI view in a neutral shoulder position, reliability results are high to excellent. The Intraclass Correlation Coefficient (ICC) values for measurements taken by one or several examiners range between 0.70 and 0.97. However, in studies' measuring the AHD in shoulder abduction, the result differs between moderate and excellent inter-rater reliability, with ICC values ranging between 0.64 and 0.92 intra-rater reliability.

In general, the previously mentioned methods suffer from some serious weaknesses: for instance, the description of transducer placement was poor and the imprecise definition of landmarks are unclear in several studies, the number of participants is small all with a relatively young age, the measurements performed in the same order are not randomised and the measurement of individual observers is not repeated between days.

It should be noted that previous studies have reported the values of subacromial space being the distance between the acromion and the head of the humeral, this refers to AHD. By using the RTUS method values ranging between 5.6 mm and 13.4 mm have been recorded, this measurement range reflects differences in the shoulder position. Muscle activity has a major effect on the AHD, the measurement technique and shoulder pathology. Moreover, RTUS has been used to quantify a reduction in AHD during arm abduction (Desmeules et al., 2004; Maenhout et al., 2012). Reduction in the AHD of less than 6 mm has been associated with SAIS patients compared to healthy individuals in studies using RTUS (Girometti et al., 2006; Pijls et al., 2010). There is an acknowledgement of the need for a methodical assessing of the reliability of AHD

measurement thus producing a more robust basis for the assessment of AHD in individuals with SAIS.

3.2 Palpation Meter examination (PALM)

Costa et al, (2010) defined the Palpation Meter (Performance Attainment Associates, St. Paul, MN) as a slide ruler that uses the values obtained from the caliper and inclinometer to calculate the vertical distance between the body structures under investigation (Costa et al., 2010). It was originally designed to measure pelvic heights and leg length discrepancies. Petrone et al. (2003) took the measurements of hip levels taken by the PALM and compared them to radiography and found excellent results (ICC=.90 and .92). In addition, the intrarater and interater reliability of the PALM were excellent (ICC=.97 and .88) (Petrone et al., 2003). The PALM is a useful tool for any clinic with a combination of a caliper and an inclinometer; however, there was only one article found in the literature which was focused on its use to measure the scapular position.

The literature review identified articles that aimed to evaluate the reliability and the usefulness of different methods for the diagnosis and evaluation of scapular position. The articles that were identified focused on measurement of the scapular position, the horizontal distance between the scapula and the spine in the scapular resting position and during elevation of the arm in the scapular plane by using different methods, which exposed methodological differences among these studies (Costa et al., 2010; Lewis et al., 2008; Nijs et al., 2005; McKenna et al., 2004; Watson et al., 2005; Sobush et al., 1996; Odom et al., 2001) amongst other. Various methods have been developed and introduced to evaluate the reliability of the instrument for diagnosis and evaluation the

static scapular position, including goniometry, palpation, radiography, photography, tape measurement, caliper and the PALM meter.

Costa et al., 2010 the author's investigated the reliability of the PALM for measuring the scapular position when the glenohumeral joint is held in several positions. Thirty normal subjects were recruited for a test-retest reliability study and the measurements were conducted by three raters on two different occasions to estimate intra- inter-rater reliability. The scapular positions were measured horizontally; this included the distance between the scapula and the spine in the scapular resting position and during elevation of the arm in the scapular plane. The results of this study indicated that measurements of the horizontal distance between the scapula and the spine were generally good for both intra-rater and inter-rater reliability. The authors conclude that the PALM is a reliable tool for the measurement of scapular positioning in a healthy sample and they point out that future studies should be conducted to further investigate the clinometric properties of the PALM in patient populations before its clinical usefulness for measuring scapular position can be established.

Lewis et al., 2008 assessed the intraobserver reliability of angular and linear clinical measurements of scapular position. Ninety Subjects were involved in this study; forty five without symptoms and forty five subjects with shoulder symptoms. Measurements were made with the patient standing, to facilitate a natural posture; series linear measurements were made using a standard non-stretch fiberglass tape measure the lateral scapular displacement and the angular measurements were made bilaterally with a commercially available gravity-dependent inclinometer. The results of this investigation showed that subjects without symptoms have ICC ranged from 0.75 to 0.98 for the angular movements for the direct linear measurements. And, for subjects

with symptoms, the ICC ranged from 0.61 to 0.98 for the direct linear measurements. This study has found very good to excellent intraobserver reliability for the angular and linear measurements of interest in both shoulders of subjects with and without symptoms. However, this study has number of limitations; the first relates to the static measurement of the scapula in standing with the arm by the side. The second limitation is that only intratester reliability has been assessed in this study.

Curtis et al., 2006 this study set out to determine the reliability of the lateral scapular slide test (LSST) using a scoliometer. Thirty-three male participated in this study; eighteen with no shoulder pain, injury, or a history of dysfunction and fifteen of the participants reported diagnoses of unilateral or bilateral shoulder pathology or injury. A test-retest, repeated measures was used by three experienced raters in three positions to test the reliability of the LSST. The results showed that measurements obtained with the LSST and a scoliometer are reliable in assessing the scapular position or symmetry. And the authors believe the LSST provides more objective measures than pure observation and can be enhanced by using a scoliometer or caliper rather than a tape measure.

Shadmehr et al., 2010 repeated measures study of fifty-seven subjects; thirty normal subjects and twenty patients, by three examiners in one session. The examiners bilaterally measured the distance between the inferior angle of the scapula and the spinous process of T7 in all three arm positions; a caliper was used to assess each measurement. Intrarater reliability of the absolute scapular distance was between good to high level in both groups. The study found low inter-rater reliability between examiners in the third test position in subjects with shoulder impairment. Sensitivity of the LSST was high for all three-test positions, but the specificity was low. The findings of this study suggest that LSST is really a two dimensional evaluation of a three-

dimensional problem, especially as the arm goes into the functional positions of abduction.

Nijs et al., 2005 examined the interobserver reliability, internal consistency, and clinical importance of three clinical tests for the assessment of scapular positioning in patients with shoulder pain. Twenty-nine patients with shoulder pain who were diagnosed by a physician as having a shoulder disorder were included in this study, two assessors performed the measurements. The distance between the posterior border of the acromion and the table, the distance from the medial scapular border to the fourth thoracic spinous processes, and the lateral scapular slide test was measured; the measurements were done bilaterally with a tape measure. The results point out interobserver reliability coefficients greater than 0.88 for the measurement of the distance between the posterior border of the acromion and the table, greater than 0.50 for the measurement of the distance from the medial scapular border to the fourth thoracic spinous, and greater than 0.70 for the lateral scapular slide test. The researchers concluded that these data provide evidence supporting the interobserver reliability of two and three tests for the assessment of scapular positioning in patients with shoulder pain.

McKenna et al., 2004 studied inter-tester reliability of Kibler's method of scapular position; fifteen junior elite swimmers were measured by three investigators. Positional measures of the scapula were made using a modification of Kibler's (1991, 1998) protocol, utilizing four arm positions and bilateral arm positioning. Subjects were tested standing using the following order; (1) arms in the relaxed position, (2) hands on hips, (3) arms in abduction and maximal internal rotation and (4) position of full elevation. Two measures using thin tape measures for each position and the distances between the medial spine of the scapula and T3/4 (Superior Kibler) and the inferior

scapula angle and T7/8 (Inferior Kibler) were recorded. The results demonstrated a similar reliability of the Superior and the Inferior Kibler measures, with intra-class correlation coefficients range (0.20–0.82). The result showed that the measurement of the scapular position in an athletic population appears to be as reliable as in non-athletic populations and the authors concluded that the present study confirms previous findings and contributes additional evidence that suggests the measurement of the scapular position in this study is reliable and adequate to confidently detect clinically important differences of 10–15 mm.

Watson et al., 2005 determined the reliability of the Plurimeter-V gravity inclinometer for the measurement of scapular upward rotation positions during humeral elevation in coronal abduction in a group of patients with shoulder pathology. Twenty six patients were assessed in two repeat tests, within a single testing session. The angle of scapular upward rotation was measured during total shoulder abduction; the measurement protocol was performed twice during a single testing session by a single tester. The results displayed very good intrarater reliability, the ICC ranged from 0.81 to 0.94 at both resting and at the end of total shoulder abduction. The writers concluded that the inclinometer can be used effectively and reliably for measuring upward rotation of the scapula in all ranges of shoulder abduction in the coronal plane.

Odom et al., 2001 used Lateral Scapular Slide Test (LSST) to determine scapular position with the arm abducted 0, 45, and 90 degrees in the coronal plane. Two groups were set up. One group had 20 subjects who were undergoing treatment for shoulder impairments and the other group had 26 subjects without shoulder impairments. A string was used to determine the linear measurement in each test and the calculation of the scapular position was based the difference of the bilateral scapular distance measurements. The researcher acknowledged that measurements of scapular

positioning based on the difference in side-to-side scapular distance measures are not reliable. Likewise, the results showed that sensitivity and specificity of the LSST measurements are poor and that the LSST cannot be used to identify people with or without shoulder dysfunction.

T' Jonck et al., 1996 identified the intratester and intertester reliability of two classic methods (Kibler and DiVeta) and additional tests (Kibler technique for the medial border, DiVeta in two positions 45° and 90° abduction and internal rotation). A sample of seventeen subjects without postural abnormalities participated in this study. The result showed that the classic Kibler method range from moderate - good for intratester and intertester reliability, and the DiVeta, procedure for the additional measures, normal scapular abduction and rotatory index were reliable when they are performed by the same clinician but, these showed low values for intertester reliability. Further research is necessary to examine the sensitivity of these tests in pathological situations

DiVeta et al., 1990 assessed sixty healthy subject and the test-retest reliability values was reported to one examiner of ICC=0.85 for scapular length and ICC=0.94 for scapular distance. The authors did not report any reliability data for the supposed end product measure of normalized scapular abduction.

Sobush et al., 1996 evaluated the Lennie test of seven different angles and distances measured using marks on the spine and scapular. The result indicated good to excellent Intra-rater reliability values ranging from (ICC=0.75 to 0.96) for the seven measures and Inter-rater ICC values ranged from (ICC=0.62 to 0.94) and proving that this test, based on radiography, is reliable.

Gibson et al., 1996 examined the intratester and intertester reliability of these four methods and examined the differences in scapular position between dominant and non-dominant extremities. Thirty-two subjects volunteered for this study. ICC revealed acceptable intratester reliability ($ICC = 0.81-0.95$) for all measurement methods. However, while one method also proved to be acceptable ($ICC = 0.91-0.92$) for intertester measurements, the other three methods were unacceptable ($ICC = 0.18-0.69$). One tester reported significant differences in the scapular position of the dominant and non-dominant extremities when using the most reliable method. The other tester found no significant differences with either method. The researcher recommended re-examining the reliability of these methods and measuring subjects with shoulder pathology.

Generally, previous studies evaluated scapular position and motion with 2-dimensional methods, using the Lateral scapular slide test (LSST) which is considered as an indirect method of examining the scapular abnormality (Kibler, 1998). LSST is a simple clinical test to evaluate scapular stability in shoulder rehabilitation protocols with less time (DePalma, et al., 2003).

The reliability and validity among these studies have shown inconsistent results, the PALM measure as reported by Costa et al., (2010) seemed to be similar to the reliability of the tape measure methods reported in previous studies and has better inter-rater reliability than the other studies that were using the tape and string for measuring the distance from the scapula to the spine, according to Gibson et al., (1995). The error in using string or tape occurs when it is pulled to produce the shortest distance between landmarks from one trial to another trial which allowed less tension to follow skin contours. As well, Shadmehr et al., (2010) study showed inconsistency in the findings with progressive arm elevation. The major reason for this

is that scapular motion, especially as the arm reaches higher levels of abduction, involves three-dimensional motions that are not in the plane of the caliper measurements.

3.2.1 Conclusions

All the studies reviewed so far, have attempted several simple clinical approaches for assessing the scapula motion and numerous techniques to measure the position of the scapula. However, there were a major differences between these studies, which made a comparison between them difficult; this was due to the type of instrumentation, different measurement procedures (i.e. use of different landmarks, measurements taken in different planes of arm elevation), and not all these studies comprised the commonly described angular and linear positions of the scapula and most of these previous studies did not give full details of how ICC was calculated, making the comparison challenging.

Following a review of the literature the following gaps were identified: the relative reliability of the RTUS measures AHD and the PALM measure the SURA in healthy individuals, the correlation between the SURA and AHD; sensitivity of the RTUS and the PALM to detect differences between patients with SIS and normal data, as well as the influence of scapular position on AHD. As a result, experimental studies were conducted to fill these gaps. This is discussed in the next chapters. The first step in this process was conducting the reliability studies.

Chapter Four

4. Reliability Studies

This chapter aimed to investigate the reliability of RTUS by measuring the AHD as well as the PALM when measuring the scapular position. This is to ensure that the changes in physical outcome measures by the end of the intervention programme are a result of tape and muscle contracting techniques rather than measurement errors. Determining the amount of measurement error would confirm that the results are from the intervention itself, (Schwartz et al., 2004).

The reliability of an outcome measurement indicates the amount to which the scores for a subject can be reproduced in the same participants in subsequent tests (Batterham & George, 2003). For an outcome measurement to be valuable, it must provide reproducible values with small errors of measurement (Rankin & Stokes, 1998). If the test cannot provide reproducibility in the same conditions as the original it cannot be considered a reliable test.

There are two types of reliability. The first type of reliability is the intra-tester reliability that shows a consistency of measures after repeated trials which are assessed by the same practitioner or investigator, and test or measurement tool (Thomas & Nelson, 2005). The interval between test and retest should remain constant to avoid random errors that may occur (Portney & Watkins, 2009). If the time period is short, important sources of error may not have sufficient opportunity to appear; equally, if the time period is too long, more sources of error than expected will affect the reliability estimate (Strube and Delitto, 1995).

The second type of reliability is the inter-tester reliability which demonstrates the reproducibility of the measurements between two or more investigators; this is when different testers would achieve the same score on the same participants (Batterham & George, 2003; Hopkins, 2000; Rowe, Durward, & Baer, 1999).

Lea and Gerhardt (1995) reported that the lack of a standardised protocol could affect inter-tester reliability (Lea & Gerhardt, 1995), as was found in a study by Riddle et al. (1987) where the training and experience of the tester and the tools used were similar but they did not follow a standardised protocol (Riddle, Rothstein & Lamb, 1987). Hence, for a tool to be used in clinical settings and research, it should display intra and inter-tester, within a day and between days reliability.

The Intra-class Correlation Coefficient (ICC) is one appropriate approach; it can be used to assess relative reliability between two or more trials. ICC reflects both the degree of consistency and agreement of measurements by assessors (Atkinson & Nevill 1998).

The ICC values are interpreted according to the following criteria: A coefficient below or equal to 0.40 is considered as representing poor reliability; between 0.40 and 0.70 is considered fair to good agreement; above 0.75 may be considered excellent agreement which is beyond chance (Fleiss, 1979).

Conversely, ICC represents insufficient information regarding the actual difference between measurements (Atkinson & Nevill, 1998). Thus, the standard error of measure (SEM) should also be considered (Rankin & Stokes, 1998), and the SEM should quantify the precision of individual scores on the test (Harvill, 1991). The SEM also, expresses measurement error using the same units of measurement of interest, whereas

the ICC is without unit (Wire, 2005). Moreover, it is not influenced by variability among participants (Stratford & Goldsmith, 1997).

The measurement error of the test is considered important when evaluating the effect of the intervention, as this will enable clinicians to evaluate accurately an individual's performance. Without the measurement error values, any changes in the performance cannot be exactly calculated, as it is unknown whether the difference was due to measurement error or a true change in performance (Munro, 2013). In order for a true change in the performance to be detected, the difference in the scores needs to be greater than the measurement error that relates to the test (Tyson, 2007). The smallest detectable difference (SDD) has been obtained to allow the determination of the change needed to indicate statistical significance (Atkinson & Nevill, 1998).

Understanding the reliability and measurement error of such-measures is important in order to establish whether the tests are valid and to facilitate future studies and clinicians to evaluate any changes in an individual. Therefore two separate studies were undertaken:

4.1 Study one: Within-day and between-day intra-tester reliability of RTUS measurements of AHD in healthy individuals.

4.2 Study two: Within-day and between day test- retest reliability of a palpation meter to measure scapular position and rotation in healthy individuals.

4.1 Study one: Within-day and between-day intra-test reliability of ultrasound scanning measurements of acromion-humeral distance in healthy individuals

4.1.1 Introduction

Sub-acromial space (SAS) is the measured interval or distance between the anterior acromion and the humeral head (Fehring et al., 2008), and is called AHD (McCreesh et al., 2013). Reduction in the Subacromial space is of clinical interest due to its association with the aetiology of SIS when the arm is elevated and the problems created which have significant impact on function, comfort, and quality of life (MacDermid et al., 2004).

Assessment of the SAS could be helpful in identifying the presence or absence of changes in AHD and could be considered as a part of the clinical shoulder joint examination. Clinicians depend upon different methods of techniques to assist diagnosis and treatment in the clinical setting. More recently there has been increased interest in the use of RTUS. RTUS is a helpful imaging tool in the evaluation of the musculoskeletal system, it has some benefits over the other imaging techniques, such as magnetic resonance imaging (MRI), radiography, and computed tomography, all of which are non-invasive and have no reported risk of exposure of ionising radiation. It also has Multiplanar imaging capability, good patient acceptance, limited costs and can be performed in the clinical setting, as often as necessary (Azzoni et al., 2004; Petranova et al., 2012). In addition, RTUS offers an excellent resolution and a possibility for real-time dynamic examination of the joints and surrounding soft tissues enabling an action view of the muscle architecture and contractions during examination and treatment (Petranova et al., 2012; Talbott et al., 2013).

An important initial step in developing the use of RTUS further is to evaluate its reliability. A reliable method of imaging the AHD using ultrasound would have multiple benefits for rehabilitation or an intervention programme for shoulder impingement syndrome.

In recent work, in a systematic review of McCresh et al. (2013), the authors identified ten published papers; seven out of ten assessed the reliability of the ultrasound to measure AHD by a single examiner (intra-rater), while the rest of the papers investigated the inter-rater reliability. The authors indicated a strong level of evidence for the intra reliability of ultrasound in the measurement of AHD when compared to other radiological methods.

So far, research has tended to focus on intra tester reliability in the same day rather than intra tester reliability between days of assessing the AHD by using RTUS. If the within day and between day reliability of this screening method is established, this will enable clinicians to use the tests with confidence and evaluate individual performance more confidently and precisely. Therefore, this study aims to:

- 1- Establish within-day reliability of the RTUS technique of the AHD in healthy individuals.
- 2- Establish between-day reliability of the RTUS technique of the AHD in healthy individuals.
- 3- Establish SEM and SDD values to facilitate clinical interpretation of AHD.

4.1.2 Method and Material

4.1.2.1. Participants

In this study a power analysis was carried out using G Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), an estimate effect size of 0.5 was used for the power analysis throughout all the studies to indicate a moderate to large difference, a significance level of 0.05, and a statistical power of 0.8 and the required sample size was calculated to be fifteen participants. Therefore, a convenient sample of 18 healthy volunteers (10 male; 8 female, all between 18 and 45 years) attended two assessment sessions within-day and between-days (a week apart) for test–retest reliability of the measurements. The chosen age range was to ensure full musculoskeletal development in the young; the age limit would assess joint degeneration or changes associated with ageing (Costa et al., 2010). The participants were all students at the University of Salford, and there was a mean age of 24.3 years (SD=6.6). Sixteen participants were right-hand dominant and the other two were left-hand dominant. The eligibility requirement for inclusion in this study was that participants must be healthy subjects with no current or recurrent history of shoulder pain or surgery; subjects with shoulder or elbow pain within six months before testing were excluded.

Ethical considerations: Approval for this study was received from the Institutional Review Board at the host University, in accordance with the latest revision of the Declaration of Helsinki (2008). All participants signed the written informed consent form prior to their participation in this study. All participants understood their rights and acknowledged their option to withdraw from the study at any time.

4.1.2.2. Instrumentation and Measurement protocol

4.1.2.2.1. Apparatus & operator

Ultrasound (US) measurement for each participant of the AHD at rest and 60 degrees of abduction were scanned by using the ESAOTE MYLAB 60 XVISION Ultrasound machine in conjunction with the PROB LA 523 LINER/7-13 MHz.

4.1.2.2.2. Measurement protocol

The protocol of the US measurement was designed by a professional physiotherapist with experience in musculoskeletal ultrasound scanning. All ultrasound scanning was performed by a sports physiotherapist (the examiner) who attended an ultrasound training course and had practiced the measurement protocol under supervision for 10 hours.

Prior to imaging capture, each subject was asked to sit with their shoulders exposed, on a customised chair with a short back support for the lumbar region, Hips and knees were positioned at 90 degrees of flexion, feet flat on the floor in the neutral trunk posture. The seated position was chosen to provide comfort to the subjects and to increase stability, as well as reducing the effect of fatigue. After adoption of the standardised position, the examiner palpated and identified the superior head of the humerus and the acromion process before each image capture.

Participants were tested in two sessions to assess within-day test-retest reliability; more tests were conducted one week apart to assess between-days reliability, in each part test all ultrasound images were saved onto an external hard drive from the ultrasound scanner for measurements to be performed offline later using Image J software. Three images were taken for each shoulder; thus, a total of six measurements were recorded for both shoulders in each position, resulting in 12 images per participant. There was

an interval of at least three minutes between each image captured, and participants were asked to reposition their arm for further measurements; between each image capture, bilateral scans of each participant were performed.

Image capture of AHD was performed in two arm positions: neutral and 60 degrees of passive abduction, the 60 degrees of passive abduction was selected based on the results of a pilot study that pointed out there was no significant difference between 60 degrees of passive abduction and 60 degrees of active abduction.

4.1.2.2.3 Measurement procedure of acromiohumeral distance (AHD)

Neutral position: Once identifying the necessary landmarks, the examiner standardised the ultrasound probe over the shoulder, on the lateral border of acromion along the longitudinal axis of the humerus to capture the images of the AHD. The transducer was manually adjusted until the echogenic borders of the acromion and the humeral head were clearly visible on the screen, this was recorded as the smallest distance between the two structures. (See Fig. 4.1.1 for neutral arm position).

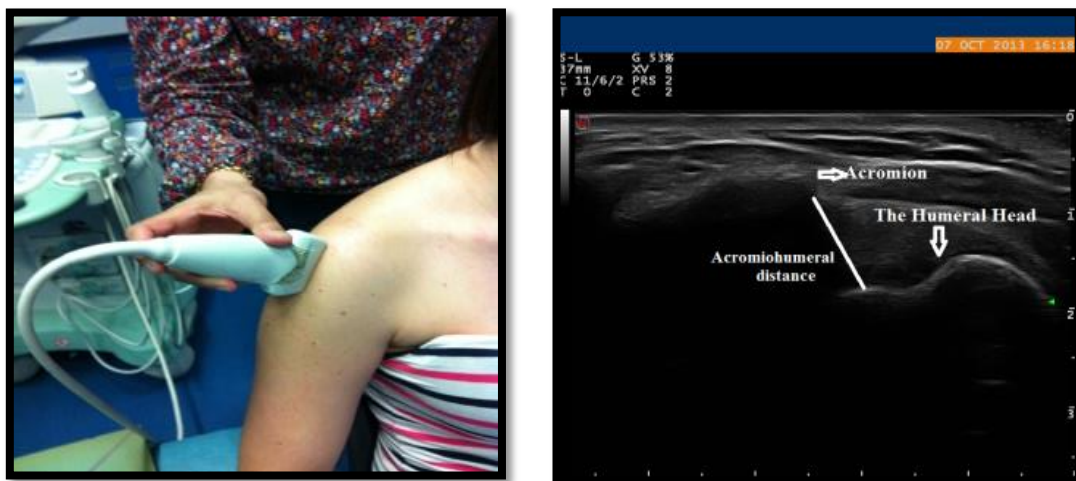


Figure 4.1.1 Ultrasound images capture of the most superior aspect of the humerus and acromion process, position (A) at rest position, the humeral head and the borders of the acromion are easily visible. The white arrow in the images indicates the distance that was measured.

Shoulder at 60 degrees of abduction: Following image capture of the rest position, the examiner positioned the arm appropriately at 60 degrees of passive abduction, the elbow was flexed to 90 degrees of flexion and the forearm rested on a wedge surface located on an adjustable table to support the arm during the testing position and a goniometer was used to ensure the correct arm position before each image capture. (See Fig. 4.1.2 for passive arm position).

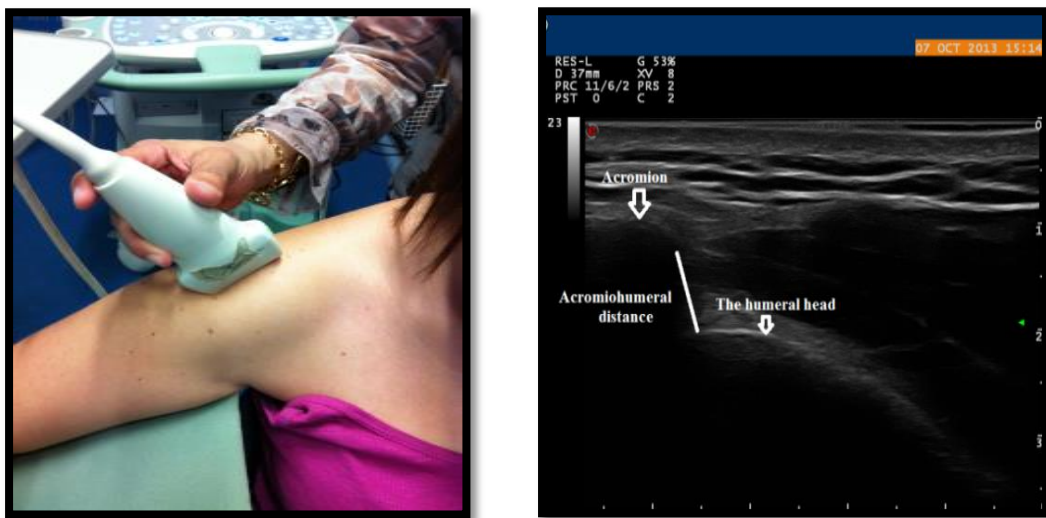


Figure 4.1.2. Ultrasound images capture of the most superior aspect of the humerus and acromion process, position (B) 60° of passive abduction. The humeral head and the borders of the acromion are easily visible. The white arrow in the images indicates the distance that was measured.

In this study, shoulder neutral and 60 degrees of shoulder abduction were chosen for the AHD measurement, because it is clinically noted that the painful arc, which may indicate a disorder of the subacromial region, is reported to start at 60 degrees of abduction (Kessel & Watson, 1977). In addition, the RTUS imaging of AHD is reported by previous authors to be less reliable at higher degrees of shoulder abduction (Duerr, 2010).

4.1.3. Data processing

Intra-class correlation (ICC) was used to calculate the reliability of the RTUS to measure the AHD with a 95% confidence interval (CI) using the Statistical Package for Social Sciences [SPSS] for Windows (Version 20.0, IBM SPSS). This is an appropriate approach which can be used to assess relative reliability between two or more trials, as it reflects both the degree of steadiness and the agreement between assessments.

A two-way mixed effect model (ICC3, 1) with absolute agreement was used to assess the within-day test-retest reliability since the same assessor performed all the measurements, and the model (ICC3, k) was used to assess the between day test-retest reliability by calculating the average of the two between-day measurements that were taken by the same assessor, in accordance with established guidelines (Shrout and Fleiss). The use of average values increases the reliability estimate by decreasing the error variance (Watkins & Portney, 2009). Hence, the reliability was assessed by calculating the measurements that were taken in the same day and between days by the same assessor for the AHD in two positions neutral and 60 degrees of passive abduction.

Reliability was interpreted using ICC values: An ICC value of greater than or equal to 0.75 was considered excellent; if the valued ranged between 0.4 and 0.75 it was considered good; a value less than 0.4 was deemed poor (Rosner, 1995). An ICC value of ≥ 0.60 was accepted, as Chinn (1991) suggests that any measure should have an ICC coefficient of at least 0.60 to be useful. In addition, in conjunction with ICC, both the SEM and the SDD were used.

The SEM is calculated from the standard deviation (SD) and reliability coefficient (i.e. the ICC) of the measured sample, as shown in this formula: $SEM = SD \times (\sqrt{1-ICC})$ (Atkinson, & Nevill, 1998). Moreover, the SDD has been obtained to allow determination of the change needed to indicate statistical significance (Atkinson, & Nevill, 1998). The following formula was used to calculate SDD: $SDD = 1.96 \times \sqrt{2} \times SEM$ (Kumar et al., 2011).

Independent paired t-tests were carried out to assess differences between (dominant - non-dominant shoulders).

4.1.4. Results

The ICC was identified for both within-day and between-day reliability of the AHD measurements on 18 healthy individual in two arm positions, neutral and 60 degrees of passive abduction. Intra rater reliability was found to be excellent for the two positions. ICC for within day reliability ranged from (0.81 - 0.85) and the ICC for between day tests retest reliability (0.76 - 0.89) respectively. SEM scores ranged from (0.22 to 0.31).

4.1.4.1. ICC within-day reliability

The test-retest ICC within-day measurements of the distance between the humeral head and the acromion in the resting ranged between 0.81 and 0.85, with SEM values of 0.28 -0.27 mm for both dominant and non-dominant arms.

For the 60° abduction position, the measurements of the distance between the humeral head and the acromion the ICC ranged between 0.84 and 0.83, with the SEM value o0.24 mm for both sides. Table 4.1.1 provides a summary of description data for within day intra-class correlation reliability.

Table 4-1.1: The Mean and standard deviation (SD), Reliability (ICC), Standard Error of Measurement (SEM) and Smallest Detectable Difference (SDD) of the distance between the acromion process and the head of the humeral (AHD) within day.

Position	Dominant arm						Non-Dominant arm					
	Mean SD (mm)	ICC	95%IC Lower Upper		SEM (mm)	SDD (mm)	Mean SD (mm)	ICC	95%IC Lower Upper		SEM (mm)	SDD (mm)
Neutral	8.9 (1.2)	.81	.84	.97	.28	.78	9 (1.2)	.85	.88	.99	.27	.75
60 degrees of abduction	7.1 (.99)	.84	.87	.98	.24	.67	7 (1.0)	.83	.87	.98	.24	.67

4.1.4.2. ICC between-days reliability

The test-retest ICC between-days for the measurement of the distance between the humeral head and the acromion was identified. In the resting position, the ICC ranged from 0.89-0.87 with the SEM values of 0.31-.29 mm for both dominant and non-dominant arms. Also, for the 60° abduction position, the measurements of the distance between the humeral head and the acromion the ICC were 0.79 and 0.76; with the SEM of 0.23-0.22 mm. Table 4.1.2 provides a summary of description data for between day intra-class correlation reliability.

Table 4.1.2: The Mean and standard deviation (SD), Reliability (ICC), Standard Error of Measurement (SEM) and Smallest Detectable Difference (SDD) of the distance between the acromion process and the head of the humeral (AHD) after one week.

Position	Dominant arm						Non-Dominant arm					
	Mean SD (mm)	ICC	95%IC Lower Upper		SEM (mm)	SDD (mm)	Mean SD (mm)	ICC	95%IC Lower Upper		SEM (mm)	SDD (mm)
Neutral	8.9 (1.3)	.89	.70	.96	.31	.86	8.9 (1.2)	.87	.65	.95	.29	.80
60 degrees of abduction	7.3 (.98)	.79	.47	.92	.23	.64	7.1 (.91)	.76	.36	.91	.22	.61

Side-to-side differences in measuring the Inferior ultrasound view showed no systematic difference between dominant and non-dominant sides for any of the three aspects. Table 4.1.3 provides a summary of description data for both sides.

Table 4.1.3: Dominant and non-dominant comparison of the average measured for the acromiohumeral distance.

Position	Mean different between Dominant and Non-Dominant arms (mm)	Std. deviation between pairs (mm)	Sig. (2- tailed)
Neutral	0.035	1.0	0.885
60 degrees abduction	0.102	1.0	0.694

The purpose of this study was to examine test-retest within day and test-retest between-days reliability (by one examiner) when using the real-time ultrasound scanning to measure the AHD in order to explore the relationship between the AHD and the SURA.

4.1.5. Discussion

The primary aim of this study was to evaluate both within-day and between-day reliability of RTUS measurement of the AHD in healthy subjects. This study found excellent within-day ICC that ranged from (0.81 - 0.88) and day-to-day ICC (0.76-.89) between repeated measurements, with SEM scores ranged from (0.22- 0.31) mm.

Within-day ICC of measuring AHD by using RTUS has been provided by a number of authors (Luque-Suarez et al 2013; Maenhout et al 2013; Leong et al 2010; White et al. 2012; Kumar, et al. 2011; Kalra 2010; Kumar, et al. 2010; Duerr 2010; Pijls et al.

2010; Seitz, 2010; Silva et al 2008; Cheng et al 2008; Girometti et al 2006; Fremont et al 2000; Michener et al 2013; Bdaiwi, et al 2014), These studies have attempted numerous simple clinical methodologies for assessing AHD. However, there was a major difference between these studies, for instance, some of these studies (Desmeules et al. 2004; Kalra et al., 2010; Leong et al., 2012; Maenhout et al., 2013; Pijls et al., 2010; Seitz et al., 2012; White et al., 2012) have measured the shortest distance between the humeral head and the acromion (AHD), while other studies (Kumar, et al., 2011; Kumar, et al., 2010; Schmidt et al., 2004) have measured the distance between the edge of the acromion and the tip of the greater tuberosity, which anatomically is considered as a longer distance (McCreesh et al., 2013). Moreover, the AHD was assessed in several arm positions, even though these positions can be calculated as passive or active with abduction. However, the methodological and positional difference between studies limits more direct comparison of the results.

Despite using various approaches, there has been a universal consensus regarding the within day reliability measurement of the AHD, all authors who have observed AHD in resting position and during several arm positions have found good to excellent intrarater reliability. This is in agreement with this study that shows excellent within-day reliability for the two positions resting and 60 degrees of passive abduction range between (0.81-0.85).

With regard to between day-reliability, only three authors (Kumar, et al. 2010; Duerr 2010; White et al. 2012) were found to have evaluated between-day reliability of the distance between the head of the humeral and the acromion in a neutral position by using the RTUS. In addition, Duerr, (2010) established the between day reliability for AHD in three arm positions: neutral, 60 degrees of passive abduction, and 60 degrees of active abduction, and the result was found to be an excellent range between 0.88 -

0.97 for day-to-day for all positions. These findings seem to be consistent with the result of the recent research which found excellent intraclass correlation.

Considering the SEM, Duerr, (2010) identifies low within-day and between day SEM for AHD in three arm positions: neutral – 60 degrees of passive abduction, and 60 degrees of active abduction ranging from 0.1 to 0.3 mm, the present study within-day and between-day SEM values ranging from 0.2 to 0.3 in two arm positions neutral and 60 degrees of passive abduction for healthy subjects compare positively with the previous investigation.

Duerr (2010) study also provides both within and between-day SDD for AHD in three arm positions: neutral – 60 degrees of passive abduction, and 60 degrees of active abduction. The SDD for AHD in neutral and 60 degrees of passive abduction ranging from 0.5 to 0.9 mm these findings seem to be consistent with the current research which found the SDD ranging approximately from 0.6 to 0.8 mm, for these two arm positions. The relatively low SEM and SDD values suggest that the method is able to detect a real difference between measurements. This is vital because the most likely application of the RTUS method is to measure differences in AHD before and after an intervention (Duerr, 2010). Changes beyond the SDD represent the amount by which a participant's measure needs to change to be sure the change is greater than measurement error (Wu CY et al., 2011).

In line with the results of the previous articles, in general this study found excellent within and between-day reliability of the AHD in all positions, which is in agreement with the results obtained by previous research, suggesting this method may be used in future research. Thus, the author can be confident that the measure is stable between

different days, this mean that the overall measurement error of the test will be minimised.

The study confirms a previous finding that suggests RTUS is reliable software for the measurement of the AHD. The most important limitation lies in the fact that the test condition was adhered to in the same order, it is suggested that the association of these factors is investigated in future studies. The current investigation also was limited in assessing the interrater reliability. Future studies should consider the interrater reliability of RTUS measurements of the AHD distance. Finally, additional studies should determine the sensitivity to change and minimal clinically important difference (Lexell & Downham, 2005) for AHD to aid in the interpretation of interventional study results.

4.1.6 Conclusion

RTUS of the AHD provides a reliable and direct investigation; this study provides new knowledge of within- and between-day reliability for AHD in healthy individuals. These results support the use of RTUS to measure AHD, with excellent within and between-day reliability. This imaging technique may help clinicians evaluate intervention strategies and exercise prescriptions to minimise the risks of developing the SAIS categories.

4.2 Study two: Within-day and between day test- retest reliability of a palpation meter to measure scapular position in healthy individuals

4.2.1 Introduction

The scapula plays numerous roles in normal shoulder function; static and dynamic control of the specific motions of the scapula allows it to fulfil these roles (Kibler, & Sciascia, 2010). However, poor scapular control will often lead to shoulder pain. The Scapular resting position and motion was observed in patients with shoulder pathology, such as impingement syndrome (Watson et al., 2005; Ludewig, & Cook, 2000; Yamaguchi et al 2000). Observation and measurement of the static scapular position is considered an essential starting point in any clinical examination when investigating shoulder pathology (Kendall et al., 1993).

Many studies (Watson et al., 2005; Bagg, & Forrest, 1988; Lewis et al., 2002; Lewis, Wright, & Green, 2005; Costa et al., 2010) amongst other have used different heterogeneous methods in measuring the static scapular position, including goniometry, palpation, radiography, photography, tape measurement, Plurimeter-V and the PALM meter. However, few of these techniques are used clinically for either cost or practical perspectives (Watson et al., 2005). Other techniques such as the lateral scapular slide test do not generally include all of the angular and linear measurements and often measure only one scapular position; these techniques are also not readily available to clinicians (Ludewig, & Cook, 2000; McKenna, Cunningham, & Straker, 2004).

Several authors (DiVeta, Walker, & Skibinski, 1990; Kibler, 1991; Kibler, 2000; Greenfield et al. 1995) have analysed various simple clinical methods of assessing the scapula position and motion. Most of them examined the scapula resting position and found good to excellent intra- and inter-rater reliability. However, fewer authors have

analysed the scapula position through the range of humeral elevation (DiVeta, Walker, & Skibinski, 1990; Kibler, 1991, Greenfield et al. 1995), this limits the validity of the findings.

When developing rehabilitation strategies to prevent and treat subacromial impingement syndrome it will be necessary to deal with the scapular motion, which appears to be important during glenohumeral elevation; this is especially true for SURA that results in elevation of the acromion (Flatow et al., 1994). However, this requires clinical measurement tools that could provide reliable evaluation of scapula motion and position (Watson et al., 2005). Therefore, the main aim of the present study was to establish the reliability of one method of measuring scapular position using the PALM at a number of shoulder elevation angles.

4.2.2 Method and Material

4.2.2.1 Study Design and Participants

4.2.2.1.1 Study design and objective

This is a test–retest reliability study looking to:

1. Establish within-day reliability of the static scapular position in a number of angles of shoulder elevation.
2. Establish between-day reliability of the static scapular position in a number of angles of shoulder elevation.
3. Evaluate the scapular rotation angle in a number of scapular positions.

4.2.2.1.2 Participants

In this study a power analysis was carried out using G Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), with an effect size of 0.5, a significance level of 0.05, and a statistical power of 0.8, the required sample size was

calculated to be fifteen participants. Therefore, a convenient sample of 18 healthy volunteers (10 male; 8 female aged between 18 - 45 years) attended two assessment sessions within day and between days (a week apart) for test–retest reliability of the measurements the age range would, to ensure full musculoskeletal development, and at 45 years, would assess joint degeneration or changes associated with ageing (Costa et al., 2010). The participants were all students at the University of Salford, and there was a mean age of 24.3 years (SD=6.6). Sixteen participants were right-hand dominant and the other two were left-hand dominant.

All participants gave written consent prior to testing and all were aware of their right to withdraw from the study at any time. To meet the inclusion criteria, participants were required to be healthy with no history of inflammatory, degenerative or neurological disease, shoulder instability or dislocation, pain or movement limitation to the shoulder and without any history of previous shoulder pathology or cervical spine pain or injury in the three months prior to participation. The study was conducted at the School of Health, Sport & Rehabilitation Sciences. The University of Salford Research Ethics Committee granted ethical approval. Demographic information such as age, gender and arm dominance was recorded.

The following factors were assessed for the arm position: arm at rest, at 60 degrees of abduction and full elevation of humerus elevation in the scapular plan. These arm positions were clinically relevant and consistent with previous literature (Boublik, & Hawkins, 1993; Kelley & Clark, 1995; Kessel & Watson, 1977). It has been suggested by Saha (1983) that the scapular plane is the most functional plane for arm elevation; therefore, in this study, humeral elevation in the scapular plane was chosen for shoulder assessment (Saha & Dutta, 1983). It is important to point out that the position of 60 degrees abduction was achieved passively. Wedges were used to support the arm

during the abduction and a bubble goniometer was placed on the subject's arm to ensure the correct position before each test.

4.2.2.2 Instrumentation and Measurement procedures

4.2.2.2.1 Instrument for measuring scapular position

The PALM calculator is a slide ruler that uses the values obtained from the caliper and inclinometer to calculate the scapula position measurement (Costa et al., 2010); this was used by the examiner to calculate the static scapular position (Figure. 4.2.1).

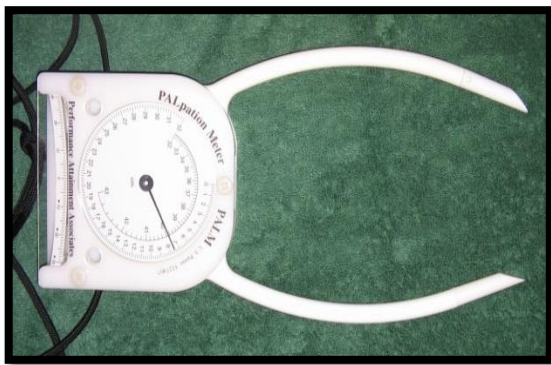


Figure.4.2.1. Palpation Meter

4.2.2.2.2 Measurement of scapula position

To determine the static scapula position measurements Kibler's (1991, 1998) test was used:

- The Inferior Kibler's: this method was modified by measuring the distance horizontally (Sobush et al., 1996).
- The Superior Kibler's: this method was added to measure the distance between the superior angles of the scapula to the thoracic vertebrae of the spine (Sobush et al., 1996; Peterson et al 1997; T'Jonck, Lysens, & Grasse, 1996).

4.2.2.2.1. Measurement procedure

PALM measurements of the scapular position were recorded for each participant in three positions: neutral position, 60 degrees of abduction and full elevation. Each subject was asked to expose their shoulder and then adopt a comfortable sitting position; Hips and knees were positioned at 90 degrees of flexion. The seated position was chosen to provide comfort to the subjects and to increase stability, as well as reducing the effect of fatigue. This position was maintained throughout testing procedures, and a value of three measurements was recorded for each shoulder (in total six measurements for both shoulders). The examiners palpated and identified the following anatomical points before the trial started in order to designate them with an alphabetical reference (Figure 4.2.2):

- **The root of the spine to inferior angle (RS-IN)**
- **The root of the spine to vertebrae thoracic of spine (RS-TS)**
- **Inferior angle to thoracic vertebrae of spine (IN-TS)**

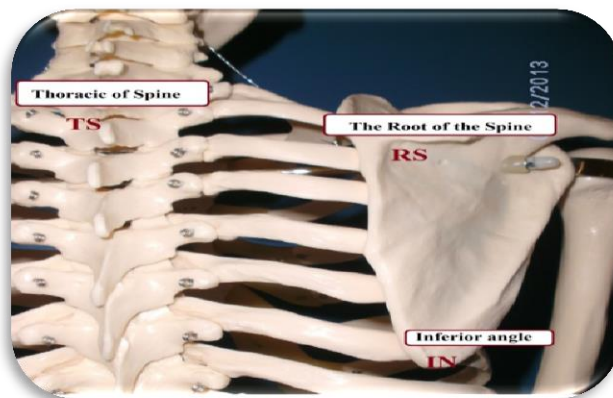


Figure.4.2.2. Anatomical landmarks used for the measurement of scapular: the root of the spine (RS), inferior angle of the scapula (IN), corresponding marks on the vertebral column (TS).

After identifying the necessary landmarks, the examiner standardised the PALM by placing the end of one arm of the PALM above one of the landmarks and the end of the other arm over the other landmark on the surface of the shoulder girdle to measure the distance between the landmarks.

- **The root of the spine to Inferior angle:** measured the distance between the inferior angles of the scapula to the root of the spine in the resting position (Figure 4.2.3).

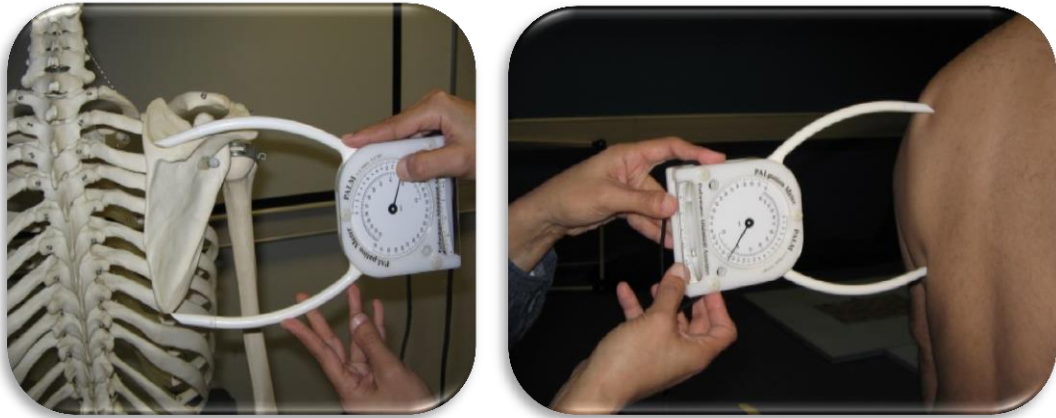


Figure.4.2.3. Anatomical reference points used to measure the distance (RS-IN) through the scapular plane.

- **Spine to the root of the spine:** measured the horizontal distance between the root of the spine to the thoracic vertebrae of the spine in the resting, 60 degrees abduction and full elevation positions (Figure 4.2.4).



Figure.4.2.4. Anatomical reference used to measure the distance (RS-TS) through the scapular plane.

- **Spine to Inferior angle:** measured the horizontal distance between the inferior angles of the scapulae to the central thoracic of the spine in the resting, 60 degrees abduction and full elevation positions. (Figure 4.2.5)



Figure.4.2.5. Anatomical reference used to measure the distance between (IN-TS) through the scapular plane

4.2.2.2.2 Measurement protocol of the scapula

Three measurements were taken for both shoulders before and after a time interval of at least three minutes on the same day to assess within-day test–retest reliability and also with a week between each test to assess between-days reliability; each subject was asked to change the order of arm positions for further measurements. All participants were measured by one examiner; three consecutive measurements were acquired in each arm position for each subject with two sessions and were recorded on a separate standardised data collection sheet. Prior to data collection, the devices were checked to ensure that they were centred in 0 and vertically aligned in this position. This investigation involved measuring a series of linear measurement between identified landmarks, as previously explained, in the following positions:

4.2.2.2.2.1 Measurement of the scapular resting position

For the first test position, the subjects were positioned as previously mentioned; the test was performed with the subject sitting and instructed to keep their arms relaxed at

their sides. After the test position was obtained and the anatomical landmarks were identified by the examiner, the distance between the following landmarks was measured horizontally in the scapular plane by using the PALM meter: **(Line RS – IN)**, **(Line RS-TS)** and **(Line IN-TS)**.

4.2.2.2.2.2 Measurement during arm abduction

For the test at 60 degrees abduction: Following the rest position, the examiner positioned the arm appropriately at 60 degree of passive abduction, the elbow was flexed to 90 degrees of flexion and the forearm rested on a wedges surface located on an adjustable table to support the arm during the testing position and a goniometer was used to ensure the correct arm position.

After adopting the test position and the landmarks identified the distance between the following landmarks **(Line RS – IN)**, **(Line RS-TS)** and **(Line IN-TS)** were measured horizontally in the scapular plane by using the PALM meter: The palpation procedure for the identification of landmarks was used as previously described. (See Fig. 4.2.6. for passive arm position).

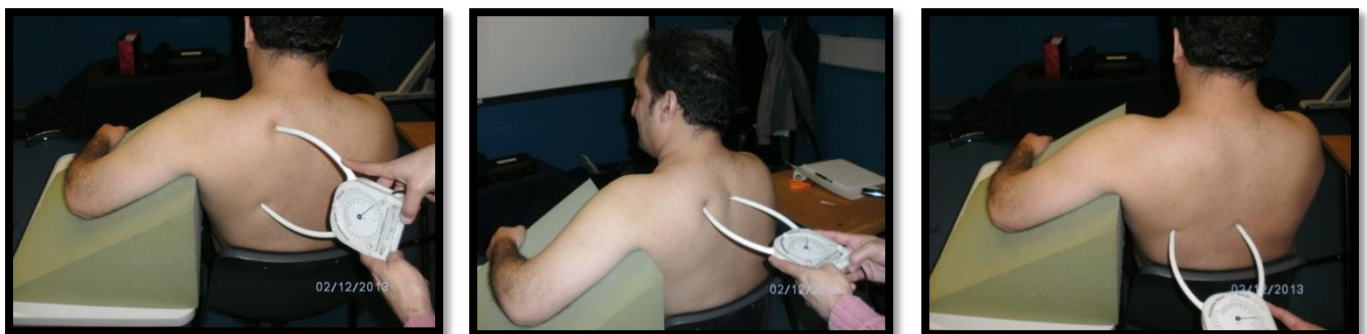


Figure.4.2.6. Show reference poles used to identify the distance between the following landmarks (Line RS – IN), (Line RS-TS) and (Line IN-TS) at 60 degrees of passive abduction.

4.2.2.2.2.3. Measurement of scapular position during full elevation

For full elevation position, while maintaining the same resting position procedure, the examiner asked each participant to elevate their arm as high as possible with their thumb raised, trying not to move their spine. The whole process was repeated two additional times resulting in three measurements of each sitting test condition and these measurements took approximately 20 minutes.

4.2.2.2.2.4 Measuring of scapular upward rotation angle (SURA)

The protocol described above for measuring scapular position was used to calculate SURA for each participant in three positions: neutral position, 60 degrees abduction, full elevation. (Figure 4.2.7)

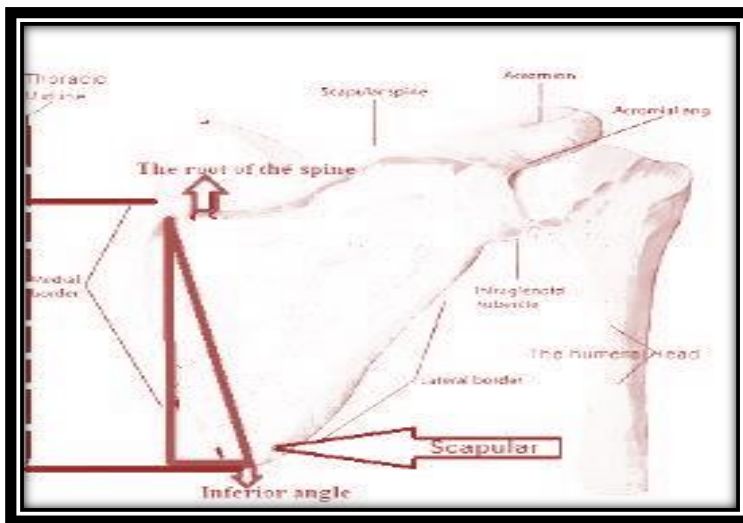


Figure.4.2.7. Calculation of the scapular rotation angle.

Calculation of the scapular rotation was performed through the knowledge of the distance between the thoracic spine and the root of the spine (TS_RS), the distance between the thoracic spine and the inferior angle of the scapula (TS_IN), and the distance between the root of the spine and the inferior angle (RSA-IN). (Figure 4.2.8)

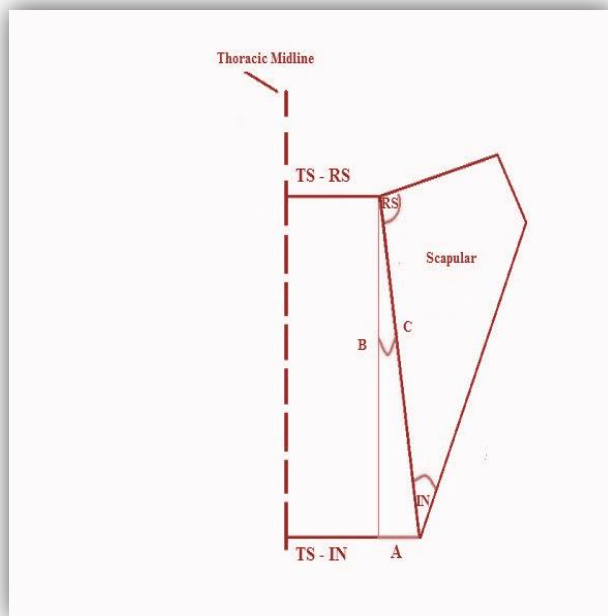


Figure.4.2.8. Calculation of the scapular upward rotation in the scapular plane was performed through the knowledge of the distance between the thoracic spine and the superior angle of the scapula (TS-RS), the distance between the thoracic spine and the inferior angle of the scapula (TS-IN) and the distance between the superior angle and the inferior angle of the scapula (RS-IN).

4.2.3. Data analysis:

First, an excel spreadsheet was used to analyse SURA for both dominant and non-dominant arms. In this study the horizontal distance was first calculated and then was identified by using this formula: $\sin(\theta) = [\text{spine to inferior distance} - \text{spine to superior distance}] / \text{spine-to-spine distance (cm)}$.

Then, the following formula: $[\text{angle } \theta = \text{ASIN}(\theta) * 180 / \text{PI} (^\circ)]$ was used to calculate the SURA in three different positions.

ICC was used to calculate the reliability of the PALM to measure the scapular position and rotation; with 95% confidence interval using the Statistical Package for Social Sciences [SPSS] for Windows [Version 20.0, IBM SPSS]. This is an appropriate approach which can be used to assess relative reliability between two or more trials, as it reflects both the degree of steadiness and the agreement between assessments.

A two-way mixed effect model (ICC3, 1) with absolute agreement was used to assess the within-day test-retest reliability since the same assessor performed all the measurements, and the model (ICC3, k) was used to assess the between day test-retest reliability by calculating the average of the two between-day measurements that were taken by the same assessor, in accordance with established guidelines (Shrout and Fleiss). The use of average values increases the reliability estimate by decreasing the error variance (Watkins & Portney, 2009). Hence, the reliability was assessed by calculating the measurements that were taken in the same day and between days by the same assessor for the AHD in two positions neutral and 60 degrees of passive abduction. Reliability was interpreted using ICC values: An ICC value of greater than or equal to 0.75 was considered excellent; if the valued ranged between 0.4 and 0.75 it was considered good; a value less than 0.4 was deemed poor (Rosner, 1995). An ICC value of ≥ 0.60 was accepted, as Chinn (1991) suggests that any measure should have an ICC coefficient of at least 0.60 to be useful. In addition, in conjunction with ICC, both the SEM and the SDD were used.

The SEM is calculated from the standard deviation (SD) and reliability coefficient (i.e. the ICC) of the measured sample, as shown in this formula:

$SEM = SD \times (\sqrt{1-ICC})$ (Atkinson, & Nevill, 1998; Kumar et al., 2011) to analyse within-subject variability and repeated PALM measurements of the static scapular position between the scores were calculated by the same assessor (Watkins, & Portney, 2009).

The SDD was used to quantify the magnitude of change that was not likely to be a result of measurement error (Kumar et al., 2011). The following formula was used:

$SDD = 1.96 \times \sqrt{2} \times SEM$ (Fletcher & Bandy, 2008).

The absolute value of the difference between the dominant and non-dominant sides was compared using a paired-samples t-test in each of the three scapular positions (neutral, 60 degrees abduction, and full elevation) respectively.

4.2.4 Result

The ICC was calculated for the scapular distance in order to assess the reliability of the measurement tools. Eighteen subjects (10 males; 8 females) with a mean age of 24.3 years old were included. Four participants were excluded from the study for the following reasons: three participants reported a history of shoulder pain, and two participants did not attend both sessions. Measurements of both dominant and non-dominant shoulders were taken from the remaining 18 participants. The study sample consisted mainly of students from the University of Salford.

4.2.4.1 Scapular position

In the resting position the Lines between the (**RS – IN**), (**RS -TS**) and (**IN-TS**) measurements were identified; however, Line (**RS -TS**) and Line (**IN-TS**) measurements were identified in three positions.

4.2.4.1.1 Scapular position ICC within-day reliability

The test-retest ICC on the day of measurement for the distance between the Root of the spine and the Inferior angle (**RS -IN**) were 0.98 and 0.99, respectively, and the SEM values ranged between 0.18 and 0.21 cm for both arms.

The distance between the root of the spine and the thoracic of the spinous process (**RS-TS**) and the distance between the inferior angle and the thoracic of the spine (**IN-TS**) at resting position ranged between 0.97 and 0.96 and the SEM values ranged between 0.14 and 0.24 cm for both arms.

For the 60 degrees abduction position, the measurement of the distance between the root of the spine and the thoracic of the spinous process (**RS-TS**) and the distance between the inferior angle and the thoracic vertebrae of the spine (**IN-TS**) at the 60 degrees abduction position ranged between 0.95 and 0.98, with the SEM values ranging between 0.13 and 0.21cm. However, in the full elevation position, the ICC for the distance (**RS -TS**) was 0.85- 0.90 for the dominant and non-dominant arms respectively, with SEM of 0.15- 0.10 cm. Finally, the ICC for the (**IN-TS**) distance, measurement for both dominant and non-dominant arms was the same (0.98), with an SEM of 0.18- 0.24 cm.

4.2.4.1.2 Scapular upward rotation ICC within-day reliability

The SURA calculations were based on the mean distances between the root of the spine and the inferior angle of the scapula (**RS – IN**), from the spine process to the root of the spine (**TS – RS**) and from the spine process to the inferior angle of the scapula (**TS - IN**).

The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were $13.6 \pm (1.8)$, $6.1 (\pm 0.78)$ cm and $7.9 (\pm 1.1)$ cm respectively, and the measurement of the upward rotation of the scapula was $8.1 (\pm 2.86)$ degrees. The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were $13.50 (\pm 1.5)$, $6.0 (\pm 0.97)$ cm and $7.9 (\pm 1.44)$ cm, and the measurement of the upward rotation of the scapular was 8.5 degrees respectively.

For 60 degrees of abduction, calculations based on the mean distances between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were 13.6 (± 1.8), 4.9 (± 0.47) cm and 9.4 (± 0.95) cm, and the measurement of the upward rotation of the scapula was 20.0 degrees respectively. The corresponding measurements for the scapular position in 60 degrees of abduction, for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were 13.50 (± 1.5), 5.1 (± 0.73) cm and 9.3 ($\pm .94$) cm, and the measurement of the upward rotation of the scapula was 19.8 degrees.

For full elevation, calculations based on the mean distances between (RS – IN), (TS – RSA) and (TS - IN) for the dominant arm were 13.6 (± 1.8), 3.9 (± 0.46) cm and 11.5 (± 1.3) cm, and the measurement of the upward rotation of the scapular was 34.9 (± 7.0) degrees respectively. The corresponding measurements for the scapular position in full elevation position for the distance between (RS – IN), (TS – RS) and (TS - IN) for the non-dominant arm were 13.5 (± 1.5), 3.5 (± 0.19) cm and 11.6 (± 1.7) cm, and the measurement of the upward rotation of the scapula was 35.60 (± 6.8) degrees respectively. Table 4.2.1 provides a summary of descriptive data for intra-class correlation reliability.

Table 4.2.1: Descriptive statistics of the outcome measurement in three tests position for the assessment of scapular positioning for both dominant and non-dominant arms within-day.

Position		Dominant arm							Non -Dominant arm						
Distance Measurements		Mean SD		ICC	95%IC		SEM	SDD	Mean SD		ICC	95%IC		SEM	SDD
					Lower	Upper						Lower	Upper		
Neutral	Line RS – IN (cm)	13.6	(1.8)	.99	.98	.99	.18	.50	13.5	(1.5)	.98	.97	.99	.21	.59
	Line TS – RS (cm)	6.1	(.78)	.97	.93	.98	.14	.37	6.0	(.97)	.95	.89	.98	.22	.60
	Line TS – IN (cm)	7.9	(1.1)	.96	.93	.98	.22	.61	7.9	(1.4)	.97	.94	.99	.24	.67
Scapular upward rotation (dg)		8.1	(2.86)	.97	.94	.99	.50	1.37	8.5	(2.9)	.98	.95	.99	.41	1.14
60 degrees abduction	Line TS – RS (cm)	4.9	(.47)	.96	.92	.98	.10	.26	5.1	(.73)	.97	.95	.99	.13	.35
	Line TS– IN (cm)	9.4	(.95)	.98	.96	.99	.13	.37	9.3	(.94)	.95	.90	.98	.21	.58
	Scapular upward rotation (dg)	20.03	(1.9)	.98	.95	.99	.25	.73	19.84	(2.9)	.99	.95	.99	.33	.91
Full elevation	Line TS – RS (cm)	3.9	(.46)	.90	.80	.95	.15	.40	3.5	(.19)	.85	.71	.94	.10	.20
	Line TS– IN (cm)	11.5	(1.3)	.98	.97	.99	.18	.51	11.6	(1.7)	.98	.96	.99	.24	.67
	Scapular upward rotation (dg)	34.9	(7.0)	.98	.95	.99	.99	2.7	35.6	(6.8)	.99	.97	.99	.68	1.9

Abbreviations: TS - thoracic spinous process, RS - Root of the spine, IN - Inferior angle, SD- Standard deviation, ICC- Intraclass correlation, SEM - standard error of the mean, SDD - Smallest Detectable Difference, dg- Degree.

4.2.4.1.3 Scapular position ICC between-days reliability

The ICC between-days was also identified, and the **(RS – IN)** line was identified just in the resting position, as mentioned before. However, the other distance **(Line RS-TS)** and **(Line IN-TS)** measurements were identified in three positions.

The test-retest ICC between-days for the measurement of the distance between the Root of the spine and the inferior angle **(RS-IN)** were 0.84-0.85, and the SEM values ranged between 0.60 and 0.46 cm for both arms. Moreover, the distance between the root of the spine and the thoracic vertebrae of the spinous process **(RS-TS)** and the distance between the inferior angle and the thoracic vertebrae of the spine **(IN-TS)** in the resting position ranged between 0.73 and 0.88 and the SEM values ranged between 0.25 and 0.49 cm for both arms. For the 60 degrees abduction position, the test-retest ICC between-days for the measurement of the distance between the root of the spine

and the thoracic of the spinous process (**RS-TS**) and the distance between the inferior angle and the thoracic of the spine (**IN-TS**) between 0.82 and 0.93, with SEM values ranging between 0.15 and 0.38 cm. However, in the full elevation position, the ICC for the distance (**RS -TS**) was 0.82-0.77, with the SEM of 0.11 and 13 cm for the dominant and non-dominant arms. Finally, the ICC for the (**IN-TS**) measurement for both dominant and non-dominant arms was the same (0.87), with an SEM of 0.40 - 0.50 cm.

4.2.4.1.4 Scapular upward rotation ICC between-days reliability

The SURA calculations were based on the mean distances between the root of the spine and the inferior angle of the scapula (**RS – IN**), from the spine process to the root of the spine (**TS – RS**) and from the spine process to the inferior angle of the scapula (**TS - IN**).

The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were $13.7 \pm (1.5)$, $6.1 (\pm 0.70)$ cm and $8.0 (\pm 1.2)$ cm respectively, and the measurement of the upward rotation of the scapula was $8.91 (\pm 2.9)$ degrees. The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were $13.60 (\pm 1.2)$, $6.0 (\pm 0.84)$ cm and $8.0 (\pm 1.1)$ cm, and the measurement of the upward rotation of the scapular was $9.2 (\pm 2.9)$ degrees respectively.

For 60 degrees of abduction, calculations based on the mean distances between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were $13.7 (\pm 1.5)$, $4.9 (\pm 0.42)$ cm and $9.4 (\pm 1.1)$ cm, and the measurement of the upward rotation of the scapula was $21.1 (\pm 3.6)$ degrees respectively. The corresponding measurements for the scapular position in 60 degrees of abduction, for the distance between (**RS – IN**), (**TS – RS**) and

(**TS - IN**) for the non-dominant arm were 13.60 (± 1.2), 5.1 (± 0.65) cm and 9.3 ($\pm .82$) cm, and the measurement of the upward rotation of the scapula was 19.5 (± 3.6) degrees respectively.

For full elevation, calculations based on the mean distances between (**RS – IN**), (**TS – RSA**) and (**TS - IN**) for the dominant arm were 13.6 (± 1.8), 3.9 (± 0.27) cm and 11.8 (± 1.1) cm, and the measurement of the upward rotation of the scapular was 35.7 (± 5.3) degrees respectively. The corresponding measurements for the scapular position in full elevation position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were 13.5 (± 1.5), 3.6 (± 0.13) cm and 11.9 (± 1.4) cm, and the measurement of the upward rotation of the scapula was 36.20 degrees respectively. Table 4.2.2 provides a summary of descriptive data for intra-class correlation reliability.

Table 4.2.2: Descriptive statistics of the outcome measurement in three test positions for the assessment of scapular positioning for both dominant and non-dominant arms between-days (one-week part).

Position		Dominant arm						Non – Dominant arm					
	Distance Measurements	Mean SD	ICC	95%IC		SEM	SDD	Mean SD	ICC	95%IC		SEM	SDD
				Lower	Upper					Lower	Upper		
Neutral	Line RS – IN (cm)	13.7 (1.5)	.84	.59	.94	.60	1.7	13.6 (1.2)	.85	.59	.94	.46	1.3
	Line RS – TS (cm)	6.1 (.70)	.87	.65	.95	.25	.70	6.0 (.84)	.73	.32	.90	.44	1.2
	Line IN – TS (cm)	8.0 (1.2)	.88	.69	.96	.42	1.2	8.0 (1.1)	.80	.47	.92	.49	1.4
Scapular upward rotation (dg)		8.91 (2.9)	.95	.91	.98	.65	1.8	9.2 (2.9)	.95	.89	.98	.64	1.8
60 degrees abduction	Line RS – TS (cm)	4.9 (.42)	.85	.60	.95	.15	.43	5.1 (.65)	.82	.52	.93	.28	.76
	Line IN – TS (cm)	9.4 (1.1)	.88	.70	.95	.38	1.1	9.3 (.82)	.93	.83	.98	.22	.60
Scapular upward rotation (dg)		21.1 (3.6)	.96	.92	.99	.71	2.0	19.5 (3.6)	.94	.86	.97	.87	2.4
Full elevation	Line RS – TS (cm)	3.9 (.27)	.82	.54	.93	.11	.32	3.6 (.27)	.77	.31	.92	.13	.36
	Line IN – TS (cm)	11.8 (1.1)	.87	.66	.95	.40	1.1	11.9 (1.4)	.87	.57	.96	.50	1.4
Scapular upward rotation (dg)		35.7 (5.3)	.95	.91	.98	1.2	3.3	36.2 (4.2)	.95	.90	.98	.94	2.6

Side-to-side differences in measuring the Scapular position showed no systematic difference between the dominant and non-dominant sides in any of the three positions for the scapular position measurement. Table 4.2.3 provides a summary of description data for both sides.

Table 4.2.3: Dominant and non-dominant comparison of the average measured distance for the scapular position.				
Position	Distance Measurements	Mean different between Dominant and Non-Dominant arms (cm)	Std. deviation (between pairs) (cm)	Sig. (2-tailed)
Resting position	Line SU-IN	0.045	0.657	0.775
	Line SU – TS	0.175	0.623	0.250
	Line IN – TS	0.066	0.636	0.665
60 degrees abduction	Line SU-TS	-0.160	0.838	0.428
	Line IN– TS	0.042	0.742	0.810
Full elevation	Line SU-TS	0.386	0.393	0.101
	Line IN– TS	-0.096	0.514	0.437

4.2.5 Principle findings

The current study found a high degree of examiner reliability during the test-retest within-day and test-retest between-days when using the PALM for measuring scapular position in a number of angles of shoulder elevation.

It was hypothesised that there would be an agreement between repeated measurement scores in measuring scapular position in different angles of shoulder elevation when the (PALM) device was used by the same examiner.

The ICC value for three different trials to measure the scapular position and rotation score of the three distance (**RS -IN**), (**RS -TS**) and (**IN-TS**) using the PALM device in neutral, 60 degrees abduction and full elevation positions mostly indicated substantial

reliability; the ICC values ranged between 0.85 and 0.99. The scores of the SEM were low (0.99 degrees) for all measurements of the scapular position. This indicates that the PALM is a reliable device when used by one examiner for measuring the scapular position on the same day.

The results obtained from repeated measurements of ANOVA indicate that there was no significant difference in the scapular position measurements between the three trials in one session when measurements were obtained from the same examiner.

Between-days reliability: the agreement between repeated measurement scores of the scapula using the PALM, as measured by the same examiner for two sessions a week apart was the basis of the trial. The ICC value for three different trials to measure the scapular position and rotation score of the three distances (RS -IN), (RS -TS) and (IN-TS) using the PALM device in neutral, 60 degrees of abduction and full elevation positions mostly indicated substantial reliability; the ICC values ranged between 0.73 and 0.96. The scores of the SEM were low (1.2 degrees) for all measurements of the scapular position and rotation.

The ICC value for the two different tests for the scapular position mostly showed good to excellent reliability between-days. Also, the SEM score was relatively low for between-days measurements. This indicates that the PALM is a reliable device when used on the same day and between-days by one assessor for measuring the scapular position and rotation using different distances.

Overall, the current study showed excellent reliability, with an ICC range between 0.85 and 0.98 when measured by the same investigator in one session, and substantial reliability ranging between 0.73 and 0.96 when measured by the same examiner over two sessions. Clinically, this study showed that the PALM is a consistent device for

measuring the scapular position, in different positions by one investigator in one session or more.

4.2.6. Discussion

The ICC of measuring the scapular position has been provided by a number of authors (Watson et al., 2005; Costa et al., 2010; McKenna, Cunningham, & Straker, 2004; Kibler, 2000) amongst other. These studies have attempted several simple clinical approaches for assessing the scapula motion and numerous techniques to measure the position of the scapula. However, the type of instrumentation used varied between studies, which made making a comparison between them difficult. Furthermore different methods were used, including the actual humeral resting position, specific arm motion studied, static versus dynamic testing, and trunk position analysis (Watson et al., 2005; McClure et al., 2001).

Some authors have observed scapula resting positions and have found excellent reliability (Watson et al., 2005; DiVeta, Walker, & Skibinski, 1990; Kibler, 1991; Kibler, 2000; Greenfield et al., 1995), and others have evaluated scapula motion during the range of humeral elevation (Watson et al., 2005; DiVeta, Walker, & Skibinski, 1990; Kibler, 1991; Greenfield et al., 1995). Only one published study (Costa et al., 2010) has used the PALM to examine the test-retest reliability of scapular position; therefore, the results of this study can be used as strong evidence that PALM is reliable software for the measurement of medial/lateral displacement and depression/elevation of the acromion by one observer.

Even using various approaches, there has been a universal consensus regarding the reliability measurement of the scapular position. Hébert et al. (2002) found excellent intra-rater reliability in measuring both scapular protraction and scapular rotation (ICC=0.97). Johnson et al. (2001) demonstrated excellent intra-rater reliability in assessing scapular upward rotation in four static positions of humeral elevation. Therefore, a simple clinical assessment tool, such as a “modified” inclinometer as shown in this study, could be a reliable measurement device for assessing the upward rotation of the scapula at rest and during humeral elevation. Jonck et al. (1996) demonstrated excellent intra-tester reliability with ICC values of 0.90-0.89. Greenfield et al. (1995) and DiVita et al. (1990) achieved an ICC of 0.97-0.94, respectively, whereas Watson et al. showed excellent reliability with an ICC value of 0.88 when measuring scapular motion (Watson et al. 2005).

In line with the results of previous articles, excellent reliability was found for all scapular positions in the current study, which is in agreement with the results obtained by previous research. However, there was variability found for between-days trials being assessed at the level of the reliability in this study. Although the results of this study are useful, the current study has some limitations that should be addressed in future studies.

Future studies should consider developing the methodology used in this study to develop a standardised testing protocol for measuring both scapular position and motion that enables assessment of the reliability measurements.

□ The participants should be from different age groups; in addition, they should display different physical characteristics to increase the generalisability of the resulting dataset.

□ The measurements for all subjects should be randomised when using the PALM to avoid any possible sources of systematic bias.

Similar studies should be conducted on patients with subacromial impingement syndrome conditions. This will help clinicians and researchers to use the PALM with more confidence.

4.2.7 Conclusion

In conclusion, test-retest, within-day and between-day reliability of the PALM measurements of the scapular position and motion were found to be very reliable to measure the horizontal distance between the scapula and the thoracic of spine when assessed by one examiner in healthy individuals. These measures that were used to calculate scapular rotation were found to have an excellent within-day and between-day reliability. This device was developed to measure scapular rotation, and may possibly provide reliable evaluation of scapula position and motion which is easy to apply and is readily available in the clinic setting.

Chapter Five

5. The relationship of scapular rotation to subacromial space

5.1 Introduction

The subacromial space (SAS) is the interval between the anterior acromion and the humeral head (Fehringer et al., 2008), which is referred to as the AHD. Interposed between these two structures are the rotator cuff tendons, the long head of the biceps tendon, the bursa, and the coracoacromial ligament (Umer, Qadir, & Azam, 2012).

A linear measure between the acromion and the humeral head was used to quantify the SAS. Studies *in-vivo* have used various imaging modalities, such as radiographs (Van de, Stoel, & Rozing, 2006a; Van de & Rozing, 2006b; Petersson & Redlund-Johnell, 1984), ultrasound imaging (US) (Girometti et al., 2006; Azzoni et al 2004) and magnetic resonance imaging (MRI) (Pappas et al., 2006; Graichen et al., 2001; Graichen et al., 2005; Roberts et al., 2002), to evaluate the width of the AHD. These previous studies have found that the width of the SAS ranges between approximately 2 mm and 17 mm. This range reflects differences in age, gender, methods, and the position of the shoulder, testing conditions, shoulder pathology and the measurement technique. However, studies by Cotton & Rideout (1964), Golding (1962) and Weiner & Macnab (1970) have identified that the width of the SAS in the healthy population ranges between 6 and 14 mm, and in unhealthy shoulders, can be lower than 4–5 mm. taking into account the thickness of the tissues interposed between the superior humerus and the inferior acromion.

Desmuelles et al. (2004) found a strong positive relationship between the reduction of AHD narrowing and the functional improvement in SAIS patients. Another study by

Jobe and Pink (1993) reported that a reduction in SAS tends to increase the load on the rotator cuff tendons when the arm abduction and elevation movements are undertaken then this reduction may cause impingement. Similar studies by Graichen et al. (1999) and Hebert et al. (2002) have reported a decrease in SAS with active arm elevation in patients with SAIS, when compared to healthy shoulders. Thus, alterations in AHD appear to be related to SAIS and may be important in the therapeutic treatment and prevention of this disease (Thompson, 2010). Therefore, SAS can be considered as a key clinical interest due to its association with the aetiology of SIS when the arm is elevated and its significant impact on function, comfort, and quality of life (MacDermid et al., 2004).

Poor scapular and humeral position have been reported in subjects who have impingement syndrome (Ludewig, & Cook, 2000; Yamaguchi et al., 2000), both may influence the SAS, as, to a degree, it is determined by the interplay between the two structures (McKenna, Straker, & Smith 2009b). In addition, there is general agreement among clinicians that abnormal control of scapular motion may be associated with an increased risk of subacromial compression of the rotator cuff tendons (Karduna, Kerner, & Lazarus, 2005). Alterations in the scapular position and control afforded by the scapula stabilizing muscles are believed to disrupt the stability and function of the glenohumeral joint (Weiser et al., 1999). If the synchronous pattern of motion between the scapula and humerus is disrupted, the rotator cuff tendons might become impinged under the coracoacromial arch (Fu, Harner, & Klein, 1991).

Scapular kinematics has been found to be associated with various surrounding soft tissues and bones, such as weak scapular musculature (Yamaguchi et al., 2000; McQuade, Dawson, & Smidt, 1998) fatigue (Cohen, & Williams, 1998), changes in

thoracic and cervical spine posture (Kebaetse, McClure, & Pratt, 1999; Cook, & Ludewig, 1996, Wang et al., 1999) and uncontrolled scapular movement. In all these there is documentation that a change in scapular kinematics may lead to SAIS. Numerous investigators have studied scapular kinematics, with different techniques and methods. However, only a few studies have looked at the biomechanical consequences of altered scapular kinematics on SAS, and they have reported that a passive alteration in the scapular position may influence the SAS. For instance, a study by Atalar et al. (2009) showed that limiting the scapular motion by externally binding the scapula down to the thorax while the arm was positioned at 90 degrees caused a decrease in SAS compared to the unrestricted scapula.

Another study by Solem-Bertoft et al. (1993) has demonstrated that in four healthy individuals, positioning the scapula in protraction compared to retraction with sandbags reduced the SAS. In contrast to the previous study result, a cadaveric study by Karduna (2005) found that inducing SURA from a neutral position reduced subacromial clearance. However, other studies have argued that patients with SIS have decreased scapular posterior tilting and upward rotation compared to healthy subjects (Endo et al., 2001, Yamaguchi et al., 2000; Lukasiewicz et al., 1999), along with increased internal rotation (Endo et al., 2001³⁴, Hébert et al., 2002; Yamaguchi et al., 2000; Warner et al., 1992). As a consequence, these changes have the possibility to limit the SAS and mechanically impinge on subacromial structures. However, no studies have directly investigated the relationship between the SAS and SURA.

Overall, both the scapular position and SAS adaptations have been associated with SAIS, and a decrease in SURA is believed to be one of the factors related to SAIS and narrowing of the SAS (Forthomme, Crielaard, & Croisier, 2008). This is because the serratus anterior muscle activity is vital to prevent the humeral head from impinging on

the acromion during arm elevation and excessive winging or anterior tilting leads to a relative decrease in the SAS (Kamkar, Irrgang, & Whitney, 1993).

Ludewig et al. (2000) and Johnson et al. (2001) have suggested that upward rotation of the scapula is clinically important because the scapula must rotate adequately in an upward fashion to prevent the humeral head from compressing and shearing against the under-surface of the acromion process during humeral elevation.

Thus, observation of the scapular position during humeral movement enables clinicians to assess the kinematic rhythm between glenohumeral abduction and SURA, all of which can influence the SAS (Kibler, 1998). Consequently, the aim of the present study is to determine whether there is an association between the position of the scapula and AHD in healthy subjects.

5.2. Method and Material

5.2.1. Participants

A power analysis was carried out using G Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), with a size of 0.5, significance level of 0.05, and a statistical power of 0.8, the required sample size was calculated to thirty-four participants. Therefore, the sample size in the current study 37 university students aged between eighteen and forty-five years old who participated in this study. Eighteen males and seventeen females attended one assessment session to calculate the correlation between the two variables. To meet the inclusion criteria, participants had to be healthy and with no history of inflammatory, degenerative or neurological diseases, shoulder instability or dislocation; pain or movement limitation to the shoulder.

All participants gave their written consent before the test commenced. The same entry criteria, approval and consent procedures were used throughout all studies. Demographic information such as age, gender and arm dominance (the side they normally use) was recorded. Table 5.1: Mean standard deviation (SD) - demographic data for participants.

Table 5.1: Mean, standard deviation (SD) - demographic data for participants.					
Age (20-50)		Gender		Dominant Arm	
Mean	SD	Male	Female	Right	Left
23.6	± 5.9	18	17	30	5

5.2.2 Instrumentation and Measurement procedures

The experimental procedure consisted of:

5.2.2.1. Measuring acromiohumeral distance (AHD)

For each participant, RTUS measurements of the AHD at rest and 60 degrees abduction were taken using an ESAOTE MYLAB 60 XVISION Ultrasound machine in conjunction with PROB LA 523 LINER/7-13 MHz. The AHD measurement was taken with the participant in a sitting position and the arm in a neutral position and at 60 degrees abduction while the arm was abducted passively. The protocol for RTUS measurement that had been designed through experience in musculoskeletal ultrasound scanning in the previous study which information was also used in the current study.

5.2.2.2 Measuring scapular upward rotation angle

PALM measurement of the scapular position was measured for each participant in three positions: neutral position, 60 degrees abduction, and full elevation. Anatomical landmarks on subjects' scapula and thoracic spine were identified by palpation before the trial started while the subjects stood with their feet in a comfortable position. The procedure for the PALM measurement that had been described previously for measuring scapular position was also used in the current study to calculate SURA. All RTUS and PALM measurements were done by the same examiner (the researcher).

The reliability of both SURA and AHD were established previously in this project using PALM and RTUS. This intra-session (within-day) reliability for RTUS ranged from ICC = 0.93 to 0.94, while the reliability for scapular positions and rotation ranged from ICC = 0.96 to 0.99. The intra-session (between-days) reliability of the RTUS ranged from ICC = 0.73 to 0.93, while the reliability for scapular positions and rotation ranged from ICC = 0.76 to 0.95.

5.3 Data processing

For the third research question, the means and standard deviations for all measured variables were presented. AHD was analysed using Image J software and an Excel spreadsheet for both dominant and non-dominant arms.

SURA was analysed using an Excel spreadsheet for both dominant and non-dominant arms. In this study the horizontal distance was first calculated and then was identified by using this formula: $\sin(\theta) = A / C$. Finally, the formula: $[\text{angle } \theta = \text{ASIN}(\sin(\theta)) * 180 / \pi]$ was used to calculate the SURA in three different positions.

A scatter diagram and Pearson's product (correlation coefficients) analysis was calculated to determine the relationship between the clinical PALM measurements of the SURA and RTUS measurements of AHD in neutral and during the 60 degrees of passive abduction. The Correlation Coefficient (r), which is known as the Pearson product-moment, was used to calculate the relationship between the SURA and the AHD with a 95% confidence interval using the Statistical Package for Social Sciences [SPSS] for Windows [Version 20.0, IBM SPSS]. This can be defined as a linear measure of the degrees of association between two continuous variables (Portney, & Watkins, 2008).

The researcher used the correlation coefficient to quantitatively measure the strength and the direction of the relationship between the two variables. The value of (r) indicates that the correlation coefficient can range from -1 (perfect negative relationship) to 0 (no correlation), to +1 for a perfect positive correlation (Watkins & Portney, 2009).

The correlation coefficient is the direction indicator.

- 1- Correlation indicates the strength of the relationship
- 2- The p-value indicates the probability that the observed relationship could have occurred by chance and a small p-value is evidence demonstrating that the null hypothesis is false and the attributes are, in fact, correlated (Harris et al., 2004).

The correlation coefficient was defined according to the r values obtained (see Table 5.2). An r value of ≥ 0.50 was accepted.

The following general guideline was used to interpret the correlations respectively:

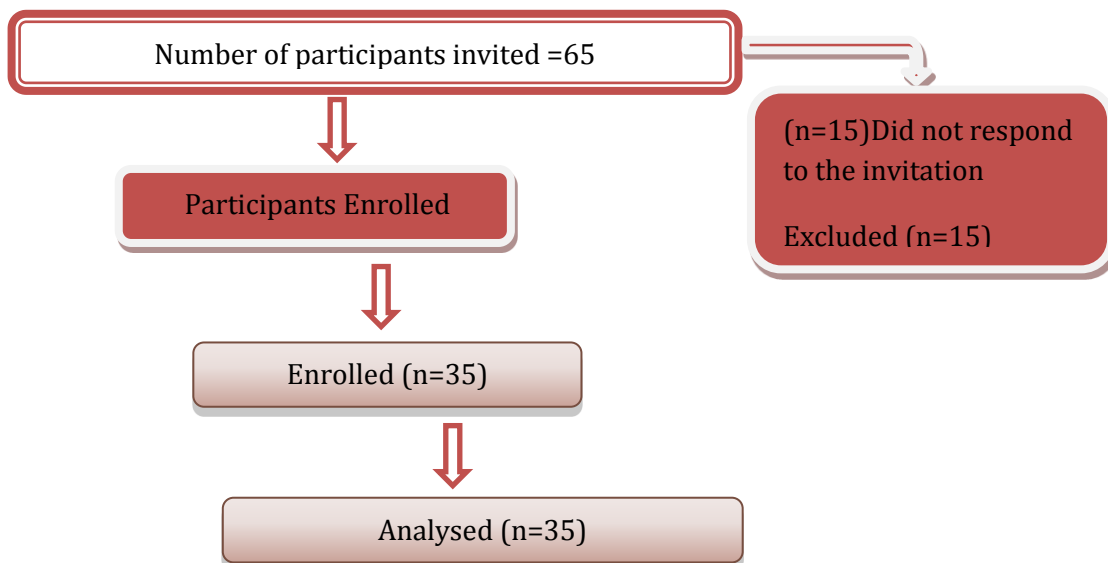
Table 5.2: Pearson's correlations (r) values and corresponding levels (Hopkins et al., 2009).

(r) Value	Value Interpretation
0.00 to 0.30	Little or no relationship
0.30 to 0.50	Fair relationship
0.50 to 0.70	Moderate to good relationship
Above 0.70	Good to excellent relationship

5.4 Results

Fifty participants were recruited into the study, of whom thirty-five completed the study: seventeen females and eighteen males with a mean age=23.6 and SD=±5.9 years. Thirty participants were right hand dominant and five participants were left hand dominant. The remaining fifteen participants dropped out of the study; ten did not attend the whole assessment for personal reasons and five participants dropped out during the assessment because they had problems with their shoulders on the day of the test.

Figure 5.1: Flow chart of study recruitment.



The AHD measurements were identified in two positions, while the scapular position was identified in three positions for both dominant and non-dominant arms. Tables 5.3 and 5.4, below, provide a summary of the descriptive data for the means and the standard deviations (SD) for all variables listed below. The current study also identified the relationship between the AHD and SURA measurements in neutral and at 60 degrees of passive abduction.

5.4.1 Acromiohumeral distance (AHD)

The descriptive data for the AHD are presented in Table 5.3. The measurement for both resting position and 60 degrees abduction calculations were based on the mean distances between the humeral head and the acromion. The corresponding measurements in the resting position (neutral position) for the dominant and the non-dominant arm were 8.21 and 8.03 mm respectively.

For 60 degrees of abduction the corresponding measurements for the dominant and the non-dominant arm were (6.97 and 6.68) mm respectively. Table.5.3 provides discursive data for the means and standard deviations for the distance between the humeral head and the acromion (AHD) dominant and non-dominant arms measurement.

Table 5.3: Means and standard deviations (SD) of the distance between the humeral head and the acromion (AHD) for the dominant and non-dominant arms measurement

Position	Dominant arm		Non- Dominant arm	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
Neutral	8.21	(1.21)	8.03	(1.66)
60 degrees of abduction	6.97	(1.11)	6.68	(1.27)

5.4.2 Scapular upward rotation angle (SURA)

The descriptive data for the scapular SURA are presented in Table 5.4. These values are for both scapula sides; SURA calculations were based on the mean distances between the root of the spine and the inferior angle of the scapula (**RS – IN**), from the spine process to the root of the spine (**TS – RS**) and from the spine process to the inferior angle of the scapula (**TS - IN**).

The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were 13.61 (\pm 2.11cm), 6.36 (\pm 0.66 cm) and 7.94 (\pm 0.61 cm) respectively, and the measurement of the upward rotation of the scapula was 6.70 degrees. The corresponding measurements for the scapular position in the resting position for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were 13.70 (\pm 1.94cm), 6.32 (\pm 0.80 cm) and 7.95 (\pm 0.88 cm), and the measurement of the upward rotation of the scapular was 6.84 degrees respectively.

For 60 degrees of abduction, calculations based on the mean distances between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were 13.61 (\pm 2.11cm), 4.94 (\pm 0.52 cm) and 9.45 (\pm 0.94 cm), and the measurement of the upward rotation of the scapula was 19.02 degrees respectively. The corresponding measurements for the scapular position at 60 degrees of abduction for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were 13.70 (\pm 1.94), 5.11(\pm 0.64 cm) and 9.64 (\pm 1.08 cm), and the measurement of the upward rotation of the scapula was 18.74 degrees respectively.

For full elevation, calculations based on the mean distances between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the dominant arm were 13.61 (± 2.11 cm), 4.14 (± 0.60 cm) and 11.44 (± 1.54 cm), and the measurement of the upward rotation of the scapular was 32.51 degrees respectively. The corresponding measurements for the scapular position in the full elevation for the distance between (**RS – IN**), (**TS – RS**) and (**TS - IN**) for the non-dominant arm were 13.70 (± 1.94 cm), 4.05 (± 0.85 cm) and 11.59 (± 1.40 cm), and the measurement of the upward rotation of the scapula was 33.90 degrees respectively. Table 5.4 provides descriptive data of the outcome measurement in three test positions for the assessment of scapular position measurement for both dominant and non- dominant arms.

Table 5.4: Descriptive statistics of the outcome measurement in three test positions for the assessment of scapular position measurement for both dominant and non-dominant arms

Position	Measurement	Dominant arm		Non-Dominant arm	
		Mean	SD	Mean	SD
Resting position (cm)	RS – IN	13.61	2.11	13.70	1.94
	TS – RS	6.36	0.66	6.32	0.80
	TS - IN	7.94	0.61	7.95	0.88
Angle (Degree)	SURA	6.70	1.46	6.84	2.01
	TS – RS	4.94	0.52	5.11	0.64
	TS - IN	9.45	0.94	9.46	1.08
60-degree abduction (cm)	SURA	19.02	3.38	18.74	3.41
	TS – RS	4.14	0.60	4.05	0.85
	TS - IN	11.44	1.54	11.59	1.40
Full elevation (cm)	SURA	32.51	7.00	33.90	7.70

Abbreviations: TS - thoracic spinous process, RS = the root of the spine, IN = Inferior angle, SD= standard division, SUR=scapular upward rotation.

5.4.3. Correlations between AHD and SURA

In this study, the AHD was correlated to the SURA at neutral and 60 degrees of abduction for both dominant and non-dominant arms.

The correlation coefficient for SURA and AHD at neutral position and 60 degrees of abduction is given as ($r = 0.29$ and $r = 0.35$) / ($r = 0.544$ and $r = 0.552$) for dominant and non-dominant arm respectively. The r indicates the correlation coefficient (Harris et al., 2003).

There was a fair relationship between SURA and AHD at 0.0 degrees abduction of the humeral head elevation: the correlations indicated were ($r = 0.29$, $p = 0.086$) for the dominant arm and ($r = 0.35$, $p = 0.036$) for the non-dominant arm. These correlations are presented in Table 5.5.

Table 5.5: Means, with standard deviations (SD), correlations (r) between scapular upward rotation and acromiohumeral distance and the p values in neutral position for the dominant and non-dominant arms.

Position	Dominant arm					Non-Dominant arm			
	Measurement	Mean	SD	(r)	P values	Mean	SD	(r)	P values
Neutral	SURA (Degree)	6.70	1.46			6.84	1.96		
				.29	.086			.35*	.036
	AHD (mm)	8.21	1.21			8.2	1.70		

* Denotes significance ($p < 0.05$) for neutral position.

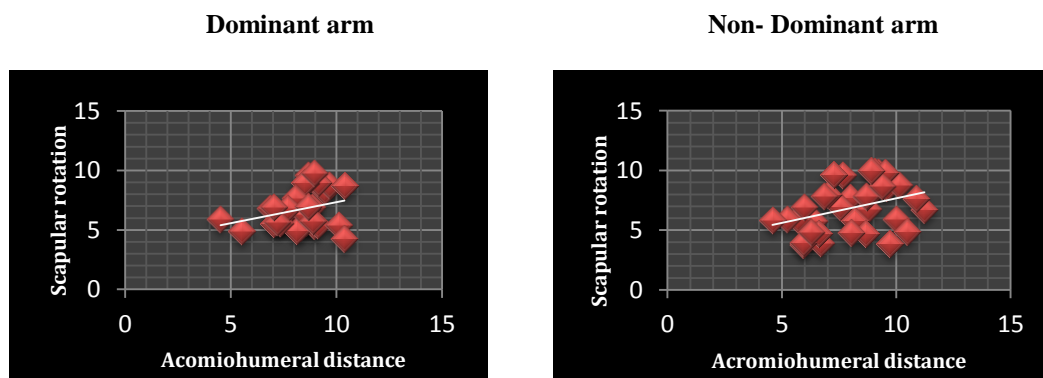


Figure: 5.2- Graph of regression of scapular upward rotation on acromiohumeral distance in neutral position

There was a moderate relationship between SURA and AHD at 60 degrees abduction of the humeral head elevation: the correlations indicated were ($r= 0.544$, $p=0.001$) for the dominant arm and ($r= 0.552$, $p=0.001$) for the non-dominant arm. These correlations are presented in Table 5.6.

Table 5.6: Means, with standard deviations (SD), correlations (r) between scapular upward rotation and acromiohumeral distance and the p values at 60 degrees of abduction for the dominant and non-dominant arms.

Position	Dominant arm					Non-Dominant arm			
	Measurement	Mean	SD	(r)	P values	Mean	SD	(r)	P values
60 degrees abduction	SURA (Degree)	19.02	3.38			18.7	3.41		
				.544	.001			.552	.001
	AHD (mm)	6.97	1.11			6.68	1.28		

**Correlation is significant at the 0.01 level (2-tailed).

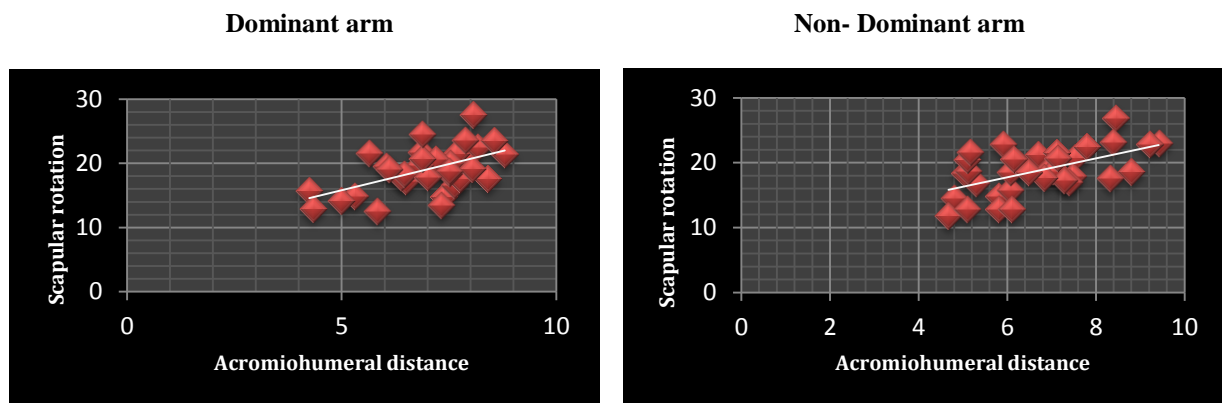


Figure: 5.3 Graph of regression of scapular up ward rotation on acromiohumeral distance at 60 degrees of abduction.

The scatter diagram for SURA and the AHD (Fig. 5.3) suggests there is a positive linear relationship between these variables.

The current study demonstrated moderate correlations between the AHD and SURA in both dominant and non-dominant arms at 60 degrees of abduction. The p-value of

$p < 0.001$ indicates that these r values would have occurred by chance 1 in 1000 times if there were really no correlation.

5.5. Discussion

The aim of this study was to examine the relationship between SURA and the AHD measurements of the shoulder elevation occurring in the scapular plane. SURA to the AHD showed a moderate correlation at 60 degrees abduction of humeral head elevation.

5.5.1. Acromiohumeral distance

The current study identified a decrease in AHD with increasing elevation angle from 0 to 60 degrees during passive arm abduction. This view is supported by Umer et al. (2012) and Graichen et al. (2001), who report that changes in the subacromial space occur in subjects with healthy shoulders; and a decrease in the width of the acromio-humeral interval occurs during glenohumeral abduction. Based on the analysis of the statistical data resulting from ultrasound examination, it was possible to conclude that even the healthy population presented a slight decrease in subacromial space measurement during arm elevation.

5.5.2 Scapular upward rotation angle (SARA)

These results identified statistically significant differences in SURA across the shoulder elevation. A greater increase in SURA as the shoulder reached greater amounts of elevation in the scapular plane was detected; this is consistent with the scapula's role, as it relates to improving the function of the glenohumeral joint during overhead activity (Borsa, Timmons, & Sauers, 2003). Similarly to this study, a relative overall increase in SURA in a study by Johnson et al. (2001) that had been detected

with modified digital inclinometers, was noted as well as in studies (Braman et al., 2009; Ebaugh, McClure, & Karduna 2005) using electromagnetic tracking systems.

Most studies show an increase in mean SURA values ranging from 2.8° to 40° at rest to 140° of arm elevation. For instance, Johnson et al. (2001) reported an increase in mean SURA values ranging from $2.8^{\circ} \pm 6.1^{\circ}$ at resting position up to $39.1^{\circ} \pm 8.4^{\circ}$ at 120° of elevation of the humeral head in healthy shoulders. Another study by Braman et al. (2009) found that the average SURA increased significantly during overhead reaching from $11.4^{\circ} \pm 5.8^{\circ}$ to a maximum of $48.6^{\circ} \pm 4.0^{\circ}$.

In a study by Ebaugh et al. (2005), there was more upward rotation of the scapula, external rotation of the scapula, clavicular retraction and clavicular elevation under the conditions of active arm elevation, and SURA was most pronounced through the mid-range (90-120 degrees) of arm elevation. Lukasiewicz et al (1999) reported a mean SURA of $28.2^{\circ} (\pm 8.4^{\circ})$ from rest to 120° of arm elevation in a mixed group of subjects with unimpaired and impaired shoulders. Scibek and Carcia (2012) observed increases in total SURA as the level of shoulder elevation increased; however, these increases varied considerably between observed increments.

In contrast, Borsa et al. (2003) reported considerably less SURA during arm elevation in the scapular plane than this current study, despite using similar instrumentation, technique and testing protocol (Johnson et al., 2001), as well as other studies that used different instruments (Ludewig & Cook, 2000; Bagg & Forrest, 1988; Doody, Waterland & Freedman, 1970). In general, previous studies have reported an increase in the values of SURA: this is consistent with the results from this study, in spite of the use of different instrumentation and experimental procedures among these studies.

5.5.3 Correlation between the scapular upward rotation and acromiohumeral distance

It was hypothesised that significant correlations exist between SURA and AHD during a 60 degrees abduction of humeral head elevation. The result of the current study is consistent with the hypothesis that there is a significant correlation between SURA and the AHD measurement.

A few studies have been conducted to determine the relationship between scapular kinematics and the AHD in a variety of ways. However, it is unclear which scapular motions positively increase subacromial space and which negatively decrease subacromial space. In reviewing the literature to date, it appears that only two studies have directly examined the influence of passive alterations of the scapula on subacromial space in healthy subjects. In the study by Solem-Bertoft et al. (1993) the width and structure of the subacromial space was studied in retraction and protraction of the shoulder girdle in four healthy subjects using magnetic resonance imaging. The anterior opening of the subacromial space narrowed as the shoulder moved from a retracted to a protracted position. Atalar et al (2009) measured the effect of restricted scapular mobility during arm abduction on AHD in ten healthy volunteers. The study found that abduction of the humerus did not affect AHD when the scapula is free to move, but it does limit the scapular motion by externally binding the scapular down to the thorax while the arm is positioned at 90° compared to unrestricted scapula caused a decrease in subacromial space in healthy individuals.

Likewise, three studies have examined the effects of scapular orientation on clearance in the subacromial space and looked at the relation between these two variables. A study by Karduna et al. (2005) examined the effects of scapular orientation on

clearance in the subacromial space on eight cadavers' shoulder joints. They were tested on a mechanical testing machine (Instron, Canton, MA), by use of a method similar to a method developed previously for testing cadaveric glenohumeral joints. The study found that posterior tilting and internal rotation had no effect on subacromial space, while upward rotation decreased the subacromial space. Therefore, the authors concluded that the upward rotational movement significantly reduced the SAS, with a significant linear relationship between abnormal scapular movements and abnormalities in the subacromial space, and thus there is decrease in subacromial clearance resulting from an increase in SURA.

In another study, the influence of dynamic SURA on subacromial space in healthy baseball players was examined. Thompson (2010) examined the AHI during dynamic arm elevations in the scapular plane, with the arm positioned at the side until 90° with and without resistance. The resistance that was used ranged from 2.6 to 4.4 kg. Three consecutive trials of unloaded and loaded scaption were performed, with approximately three minutes between the unloaded and loaded conditions, in thirteen healthy baseball players with arms at 30°, 45°, 60°, and 75°. The mean AHI for both unloaded and loaded scaption decreased significantly from the arm at the side (12.7 mm) until 45° (4.9 mm); further changes in the mean AHI between 45°, 60° and 75° were not significantly different. Greater SUR is associated with better maintenance of the subacromial space during weighted scaption, and with additional weight significantly greater reductions resulted in AHI at 75°. Strong relationships between AHI and SUR with the addition of the load suggest that SUR is an important factor in AHI during dynamic arm motion.

Silva et al (2010) used ultrasonography to measure AHD in two groups: one comprising of 53 elite tennis players and a control group of 20 volunteers. A greater reduction was demonstrated in the subacromial space in the elite tennis players with scapular dyskinesis compared to players without dyskinesis and a significant correlation was found between scapular dyskinesia and the subacromial space measurement, even between the asymptomatic tennis players. However, the clinical method that was used to identify scapular dyskinesis and associated reliability was not reported.

The results from this study identified a significant correlation between the SURA and AHD during 60 degrees abduction of the humeral head elevation with a positive moderate relation. These findings are inconsistent with previous studies, but significant difference in methodology exists between these studies. For instance, some studies used subjects from a variety of the population and age groups, while other researchers combined data from both impaired and unimpaired shoulders. These differences must almost certainly have accounted for some of the variances between results.

One of the more significant findings to emerge from this study is that SURA testing in the scapular planes may be useful for observing dyskinesia scapular motion. This finding suggests that in general, 1- these biomechanical factors should be considered in the clinical evaluation and treatment of this disorder, 2- widening of the acromiohumeral distance should be considered in further investigations. 3- future studies should consider developing the methodology used in this study to develop a standardised testing protocol for measuring both scapular position and AHD that enables assessment of the association between the two measurements.

Finally, the findings in this study are subject to at least three limitations that need to be considered. First, the reduced number of participants has adversely affected the power of the study. Secondly, other factors that may influence AHD, such as dynamic muscle activity, were not tested. Thirdly, further data collection is required to determine exactly how scapular motion affects AHD.

Moreover, investigations associating scapular kinematic alterations as to the magnitude of the available AHD and the possible impinging structures are required to further clarify the clinical and biomechanical importance of kinematic alterations in the patient population in other scapular motions, such as dynamic motions, that may affect the space.

5.6. Conclusion

Returning to the hypothesis posed at the beginning of this study, it is now possible to state that there is a significant correlation between SURA and the AHD measurement. This researcher concludes that researchers should conduct more research on direct associations between shoulder kinematics and subacromial space measurements. This researcher also believes that additional studies will be required in order to confirm these findings and to link scapular kinematics and AHD prior to further clinical decisions based only on theory. Only in this way will it be possible to specifically characterise the relationship of altered scapular kinematics as an influencing factor for shoulder injuries.

Chapter Six

6. Comparison of measures in symptomatic and asymptomatic subjects

6.1. Introduction

One of the qualities of measuring instruments is their sensitivity, which can be defined as the smallest change in the actual value of a measured quantity that will produce an observable change in an instrument's indicated output (Schuck, and Zwingmann, 2003). It aims to assess the robustness of an assessment by examining the amount to which results are affected by changes in or between subgroups (Thabane et al., 2013).

There has been limited research investigating the anatomical basis of SAIS. Some research that has examined this topic has focused on the contact or distances between impinged structures (Green et al., 2003; Roberts, et al., 2002), and other studies have established the accuracy and reliability of using pressure transducers to measure glenohumeral contact pressure (Gupta and Lee, 2005; Shapiro et al., 2007).

Both, RTUS and the PALM measurements have been recently developed and found to be reliable measures in healthy populations. However, no study has been published to date detecting the sensitivity of these tools in the presence of pathology for either RTUS in measuring the AHD or the PALM in measuring scapular position. Previous studies (Kalra et al., 2010; Desmeules et al., 2004; Pijls, et al., 2010; Costa et al., 2009) have examined only the reliability or the validity of the instruments. Therefore, the research aimed to establish if any differences occurred between the injured arm in patients with SAIS and the normal data with the AHD measure by using RTUS and the scapular position measurements, using the PALM, to enable a complete picture of the clinical usefulness of these two measurement techniques.

In particular, to gain confidence of their reliability in the measurements that have been used in both rehabilitation and research settings. The results of the comparison may strengthen the conclusions of this study and the credibility of these findings. The aims of this chapter were therefore to observe and record:

1- Compare the RTUS measures AHD to detect differences between the injured arm in patients with SAIS and the normal data (healthy individuals – non injured arm in patient with SAIS) in the neutral position and at 60 degrees of passive abduction

2- Compare the PALM measures of the scapular position to detect differences between the injured arm in patients with SAIS and the normal data (healthy individuals – non injured arm in patient with SAIS) in the neutral position and at 60 degrees of passive abduction.

6.2. Method and Material

6.2.1. Study Design and Participants

6.2.1.1. Study design

This is a case study examining the differences between the normal data and patients with SAIS of both the RTUS and the PALM measurements in two arm positions (neutral and 60 degrees of passive abduction).

6.2.1.2. Participants

A convenient sample of patients with SAIS, attended one-assessment session measurements, three females - two males between the ages of 20-65 years, with mean age of 36.3 years and Standard Deviation (SD=8.4). Three participants were right-hand dominant and two participants were left-hand dominant. All were volunteers and were

recruited from the College of the Health, Sports and Rehabilitation Sciences at Salford University; they were screened for inclusion between May 2012 and August 2013.

Inclusion criteria - participants need to meet the following criteria:

- ☐ Subjective complaint of difficulty performing activities of daily living, and age (18-65) years;
- ☐ History of anterior or lateral shoulder pain persisting for more than one week during the last six months;
- ☐ Painful arc with active shoulder elevation between 60 degrees to 120 degrees;
- ☐ Pain with resisted isometric shoulder abduction;
- ☐ Positive Neer test, indicating possible supraspinatus involvement;
- ☐ Positive Hawkins–Kennedy test, indicating possible external impingement;
- ☐ Pain reproduced during supraspinatus empty can test
- ☐ Pain with palpation on the greater tuberosity of the humerus

Exclusion criteria: exclusion criteria from the study were as the following:

- ☐ History of dislocation or traumatic injuries on the tested shoulder complex;
- ☐ History of shoulder surgery within the last 6 months;
- ☐ Reproduction of symptoms in the cervical screening;
- ☐ Failure to complete the testing sessions.
- ☐ Pregnancy

Participants were given a written consent form with information about the research study, and each subject was asked to read and sign it before the test commenced, all subjects were aware of their rights to withdraw from the study at any time during the investigation. The study was conducted at the School of Health, Sport & Rehabilitation

Sciences. Approval was granted from the University of Salford Research Ethics Committee.

6.2.2 Protocol testing

First the participants had to sign the consent form, after that the researcher asked them to expose their shoulders, an experienced physiotherapist who had more than 20 years' experience dealing with musculoskeletal disorders examined the subjects for the presence of SAIS, any participants having two or more positive signs were included in this study.

6.2.2.1 Shoulder examination

A recent pooled data analysis from Hegedus et al. (2012) has indicated the sensitivity and the specificity for Hawkins-Kennedy test was 79% and 59%, and for Neer test 72% and 60% respectively. Therefore, these two clinical tests were used to assess SAIS and the results were recorded as positive or negative. i): Hawkins–Kennedy test, in which the shoulder is passively flexed to 90 degrees, then fully internally rotated (Hawkins and Kennedy, 1980). ii): The Neer sign: the shoulder is flexed passively while the scapula is stabilised (Neer, 1983). Table.6.1. provides an explanation of two clinical tests for shoulder examination.

Table.6.1: Shoulder examination				
Test	Posture	Fixation	Background	Pain
Hawkins-Kennedy: Passive internal rotation of the shoulder until pain occurs.	Seated or standing arm at 90° in forward elevation in the scapular plane.	Stabilisation of the scapula to minimise upward rotation during performance of the internal rotation plan	Supraspinatus tendon impinges against the coracoacromial ligament	During forced internal rotation.
Neer: Passive forward elevation of the arm	Seated or standing and the examiner standing.	Ipsilateral scapula to prevent protraction.	Supraspinatus and subacromial bursa impinges against the acromion.	While arm is elevated

6.2.2.2 Procedure

Once the diagnosis of the SAIS had been established, RTUS was used to measure AHD and the PALM was used to investigate the scapular position and rotation to evaluate the differences between normal data (healthy individuals group - non-injured group) and the injured arm group in two arm positions (neutral position – 60 degrees of passive abduction).

The same procedure for the placement of both the RTUS to measure AHD and the PALM to measure the scapular position were used as previously described in Chapter 4. Patients with SAIS had both arms measured.

6.3. Data analysis

Descriptive characteristics were calculated for non-injured arm group and injured arm group. And the healthy individuals' data that already explored in Chapter 5 was used to evaluate the differences between the three groups of interest (non-injured arm group, injured arm group and healthy individuals). The Statistical Package for Social Sciences [SPSS] for windows [Version 20.0, IBM SPSS] was used for all statistical analysis. Means and standard deviations for all measured variables were presented. The alpha level for all tests was set at $p < 0.05$. The t-test for the independent sample test was used for comparing the healthy group with the patient group with the injured arm and non-injured arm groups. The paired t-test was applied to compare the non-injured arm group with the injured arm group in patients with SAIS. The SEM quantifies the measurement error of an observation at one point in time, in reference to the precision of individual scores on a test, and has been used to define the limits around which a

subject's true score lies (Weir et al., 2005). Thus, it can be used to calculate a range where the true score of patients with SAIS is located at 95% CI.

The comparisons were based on the SDD; data from the reliability of both AHD and the scapular position were used to determine the SDD. The SDD demonstrated 95% CI of the difference in scores between paired observations that was previously calculated as $1.96 \times \sqrt{2} \times \text{SEM}$. (Beckerman et al., 2001; Lexell et al., 2005; Lim et al., 2005).

6.4. Result

6.4.1. Measurement of the acromiohumeral distance

The patients with SAIS were defined into two groups (non-injured arm group and injured arm group). For each group, the AHD was measured in the neutral position and at 60 degrees of abduction, and the measurements of both groups were compared with each other, and with the healthy group data that investigated in Chapter 5.

6.4.1.1 Descriptive analysis of neutral position

Table 6.2, shows that the three groups have a very close average measurement of the AHD, where the average of AHD are: healthy group is 8.21 mm with (± 1.23 SD) mm; non-injured arm group is 8.20 mm with (± 1.50 SD) mm and injured arm group is 8.28 mm with (± 1.29 SD) mm. Figure 6.1 shows how the groups are close, however the 95% CI for the non-injured and injured arm groups in patients with SAIS is wider than the healthy group because the sample size is small. The result based on using independent t-test confirms that there is no significant difference in the AHD between the healthy and non-injured groups ($t=0.017$, $p= 0.987$), and the healthy and injured arm groups ($t=0.118$, $p= 0.906$) respectively. In terms of the paired t-test, also, there is

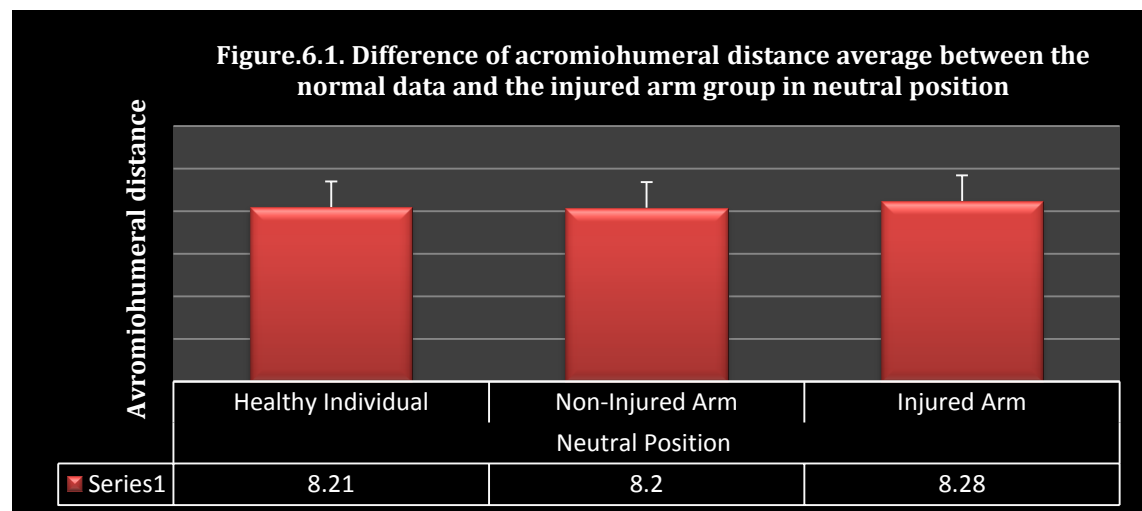
no significant difference between non-injured and injured groups ($t=0.230$, $p= 0.830$).

Table 6.2 Showing descriptive data for acromiohumeral distance in neutral position.

Table 6.2: Mean, with standard deviation (SD) values and the difference of the acromiohumeral distance between the normal data group and the injured arm group in neutral position				
Groups	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Healthy arm	8.21	± 1.23	4.51	10.38
Non-injured arm	8.20	± 1.50	7.01	10.37
Injured	8.28	± 1.29	7.10	9.95

Group Comparison	Mean differences between subgroup	t	p-value
Healthy - non-injured arm	0.01	.017	.987
Healthy - Injured arm	0.07	-.118	.906
*Non-injured - injured arm	0.08	-.230	.830

* Paired t-test is used to compare non-injured and injured arm.



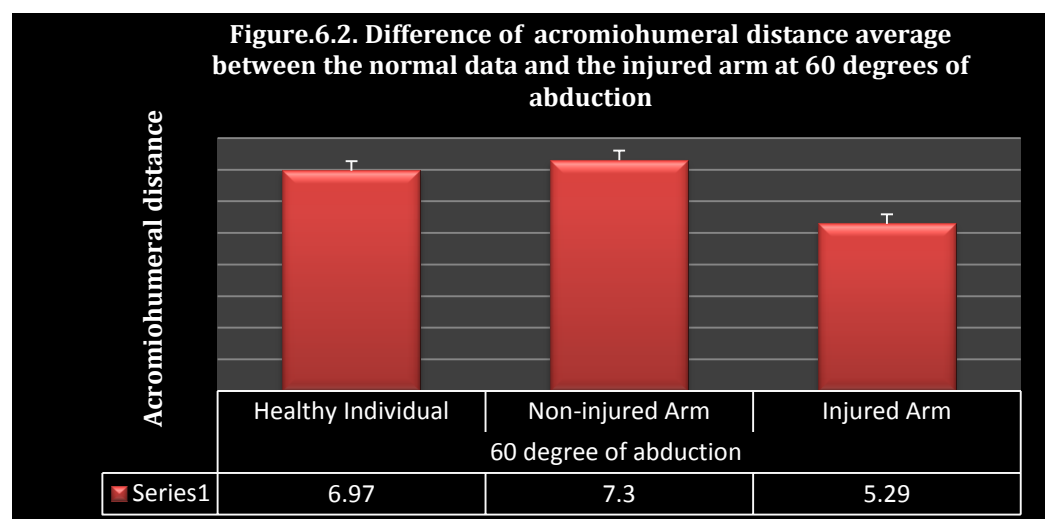
6.4.1.2 Descriptive analysis of acromiohumeral distance 60 degree of abduction

The AHD average for the healthy group and non-injured arm group are close, and were found to be 6.97 mm with (± 1.36 SD) mm for the healthy group, while it was 7.31 mm with (± 0.819 SD) mm for the non-injured arm group, no significant difference was found in AHD between the two groups ($t= 0.643$, $p= 0.524$), but they

differ from the injured arm group see Table 6.3. By looking at the measurements of the injured arm group, the average of AHD is 5.29 mm with (± 0.768 SD) mm, which is lower than the healthy group and the non-injured arm group. Differences of the AHD between the normal data (healthy group, non-injured arm group) and the injured arm group, were found to be statistically significant demonstrating that there is a significant difference in AHD between the normal data and injured arm group with ($t=3.18$, $p=0.003$ and $t=7.76$, $p=0.001$). As a consequence, the measurement of AHD at 60 degrees of abduction, for the injured group is significantly lower than the healthy and non-injured groups. (See. Figure 6.2). Table 6.3. Showing descriptive data for acromiohumeral distance at 60 degrees of abduction.

Table 6.3. Mean, with standard deviation (SD) values and the difference of the acromiohumeral distance between the normal data group and the injured arm group at 60 degrees of abduction position				
Groups	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Healthy arm	6.97	± 1.36	4.24	8.80
Non-injured arm	7.31	$\pm .819$	6.64	8.72
Injured	5.29	$\pm .768$	4.34	6.32
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	0.34		-.643	.524
Healthy - Injured arm	1.68		3.18	.003
*Non-injured - injured arm	2.02		7.76	.001

* Paired t-test is used to compare non-injured and injured arm.



6.4.2 Measurement of scapular position

6.4.2.1 Descriptive analysis scapular position of neutral position

Participants with SAIS are defined by two groups (non-injured arm group and injured arm group). For each group, the scapular position was measured in neutral position and at 60 degrees of abduction and was compared with the healthy individual group.

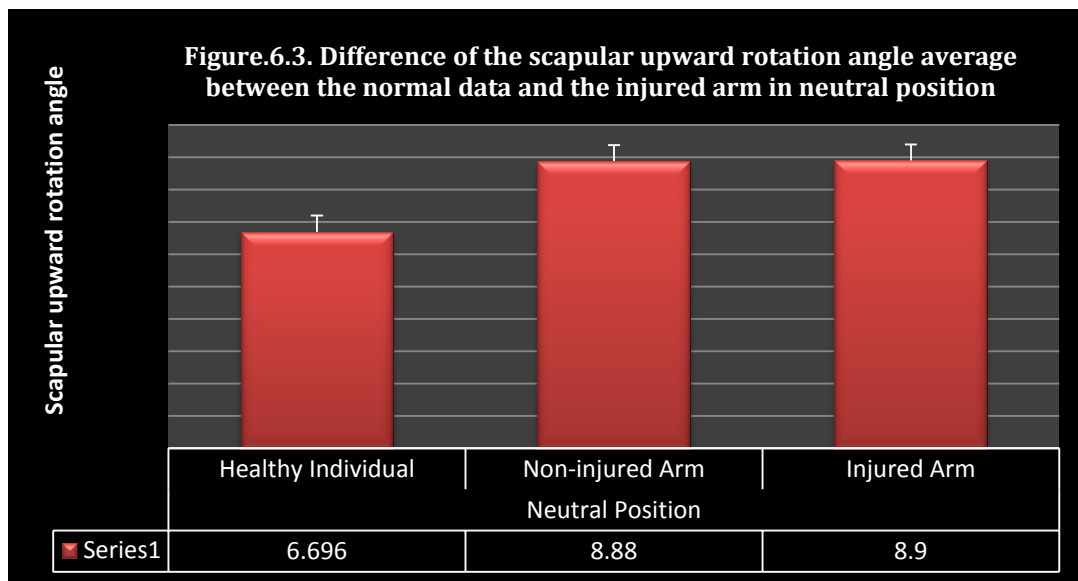
6.4.2.1.1 Scapular upward rotation angle (SURA)

The analysis of scapular rotation is given in Table 6.4; the average of SURA for the healthy group is 6.69 degrees with (± 1.46 SD). While the average of SURA for the non-injured and injured arms were very close with 8.88 (± 1.69 SD) degrees and 8.92 (± 3.5) degrees respectively. By comparing the healthy group with the non-injured shoulder, there is a significant difference between the two groups with ($t=3.05$, $p = 0.004$). Similarly a significant difference was found between the healthy group and the injured arm group with ($t=2.59$, $p = 0.013$) (See.Figure.6.3).

For patients with SAIS no significance difference in SURA was found between the non-injured group and the injured arms, with ($t=0.42$, $p= 0.969$). Table 6.4 Showing descriptive data for scapular upward rotation angle in neutral position.

Table 6.4: Mean, with standard deviation (SD) values and the difference of the scapular upward rotation angle between the normal data group and the injured arm group in neutral position				
Groups	Mean (Degree)	SD (Degree)	Min (Degree)	Max (Degree)
Healthy arm	6.69	± 1.46	4.24	9.77
Non-injured arm	8.88	± 1.69	6.37	11.00
Injured arm	8.92	± 3.50	6.37	11.42
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	2.23		-3.05	.004
Healthy - Injured arm	2.19		-2.59	.013
*Non-injured - injured arm	0.04		-0.42	.969

*** Paired t-test is used to compare non-injured and injured arm**



6.4.2.1.2 The distance between the root of the spine of the scapula and the thoracic spine (RS-TS)

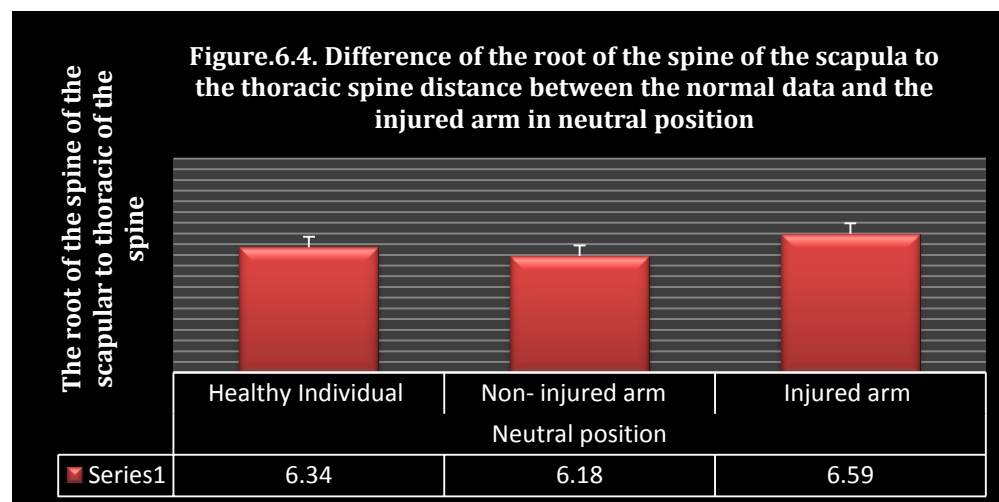
The results given in Table 6.5 shows measurement of the (RS-TS) distance which tends to have slightly different average for the injured arm than the normal data (healthy group and non-injured group). The lowest average for (RS-TS) distance is observed for the non-injured arm group which is 6.18 (± 1.25 SD) cm, and then followed by the healthy group with average distance equal to 6.34 (± 0.674 SD) cm, the normal data shows close average for the (RS-TS) distance. While the injured arm demonstrated a slightly higher average score with 6.59 (± 1.17 SD) cm, Figure 6.4 reveals that the groups of non-injured arm and injured arm have a wide 95% CI. According to the t-test, there is no significant difference ($p > 0.05$) between the groups of interest. Table 6.5 Showing descriptive data for the root of the spine of the scapula to thoracic spine in neutral position.

Table 6.5: Mean, with standard deviation (SD) values and the difference of the root of the spine of the scapula to thoracic spine distance between the normal data group and the injured arm group in neutral position

Groups	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Healthy arm	6.34	±.674	4.90	8.10
Non-injured arm	6.18	±1.25	4.20	7.27
Injured arm	6.59	±1.17	5.27	8.07

Group Comparison	Mean differences between subgroup	t	p-value
Healthy - non-injured arm	.16	0.45	.655
Healthy - Injured arm	.45	-1.27	.212
*Non-injured - injured arm	.41	-2.05	.109

* Paired t-test is used to compare non-injured and injured arm.



6.4.2.1.3 The distance between the inferior angle of the scapular and thoracic spine (IN-TS)

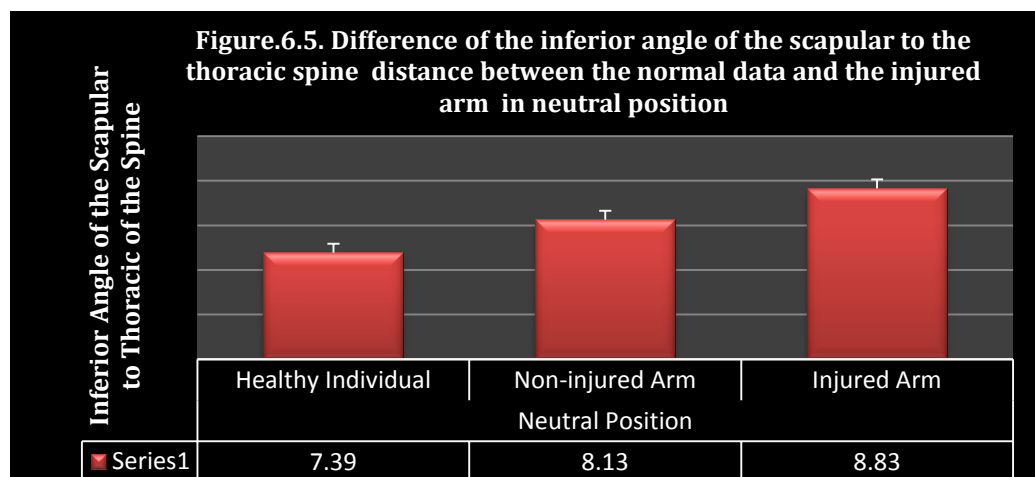
Similarly, the (IN-TS) distance for the injured arm, has the highest average which is 8.83 (± 0.767 SD) cm, then followed by the non-injured arm and healthy groups, where the averages of the normal data are very close with 8.13 (± 1.07 SD) cm and 7.93 (± 0.702 SD) cm, respectively (see Table 6.6). Based on the independent sample t-test, there is no difference between the healthy group and non-injured group ($t=0.57$, $p=0.566$), whereas there is a significant difference between the healthy individuals and

the injured arm group with ($t=2.67$, $p= 0.011$), likewise the non-injured arm and the injured arm groups with ($t=2.91$, $p= 0.044$) (see Figure 6.5). Table 6.6 Showing descriptive data for the inferior angle of scapular to thoracic of spine distance in neutral position.

Table 6.6: Mean, with standard deviation (SD) values and the difference of the inferior angle of scapular to the thoracic spine distance between the normal data group and the injured arm group in neutral position

Groups	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Healthy arm	7.93	$\pm .702$	6.97	9.30
Non-injured arm	8.13	± 1.07	6.43	9.23
Injured arm	8.83	$\pm .767$	7.99	9.73
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	.20		-0.57	.566
Healthy - Injured arm	.80		-2.67	.011
*Non-injured - injured arm	.70		-2.91	.044

* Paired t-test is used to compare non-injured and injured arm.



6.4.2.2 Descriptive analysis of 60 degree of abduction

6.4.2.2.1 Scapular upward rotation angle

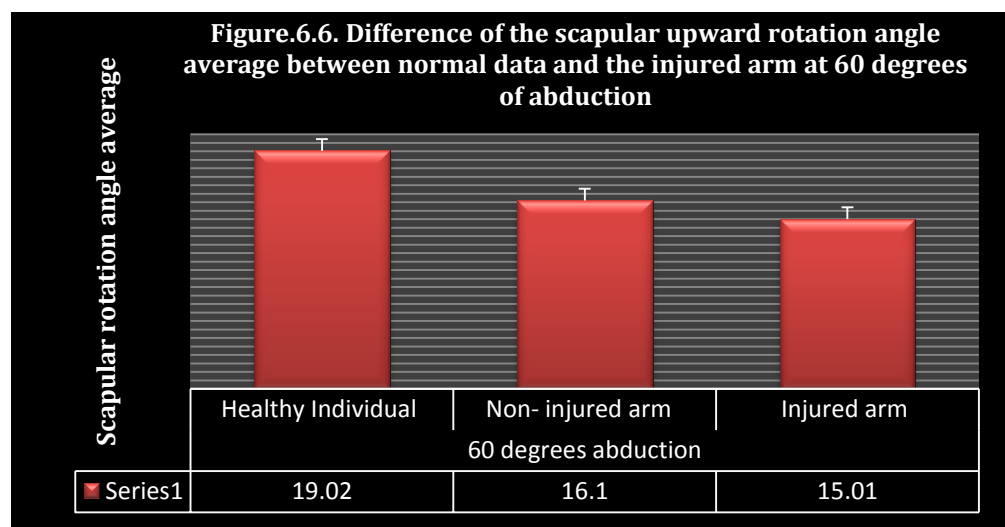
The healthy group showed the highest average of the SURA which was 19.02 (± 3.38 SD) degrees (see Table 6.7). While in patients with SAIS, the non-injured arm group

showed an average of 16.10 (± 4.29 SD) degrees, whereas the injured arm group presented a slight decrease in the average of the SURA with 15.01 (± 4.32 SD) degrees. By comparing the mean difference of the normal data (healthy group and non-injured arm group) with the injured arm group, based on the independent sample t-test, there is significant difference between the healthy individual and injured arm group with ($t=2.40$, $p = 0.022$). Moreover, the dependent subjects paired t test showed that there is significance difference in scapular rotation between the non-injured and injured arms, with ($t=3.37$, $p= 0.020$). (Figure 6.6).

Table 6.7: Mean, with standard deviation (SD) values and the difference of the scapular upward rotation angle between the normal data group and the injured arm group at 60 degrees of abduction

Groups	Mean (Degree)	SD (Degree)	Min (Degree)	Max (Degree)
Healthy arm	19.02	± 3.38	12.57	27.58
Non-injured arm	16.10	± 4.29	8.47	18.54
Injured arm	15.01	± 4.32	7.47	17.99
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	2.93		1.75	.088
Healthy - Injured arm	4.01		2.40	.022
<i>*Non-injured - injured arm</i>	<i>1.02</i>		<i>3.73</i>	<i>.020</i>

** Paired t-test is used to compare non-injured and injured arm.*



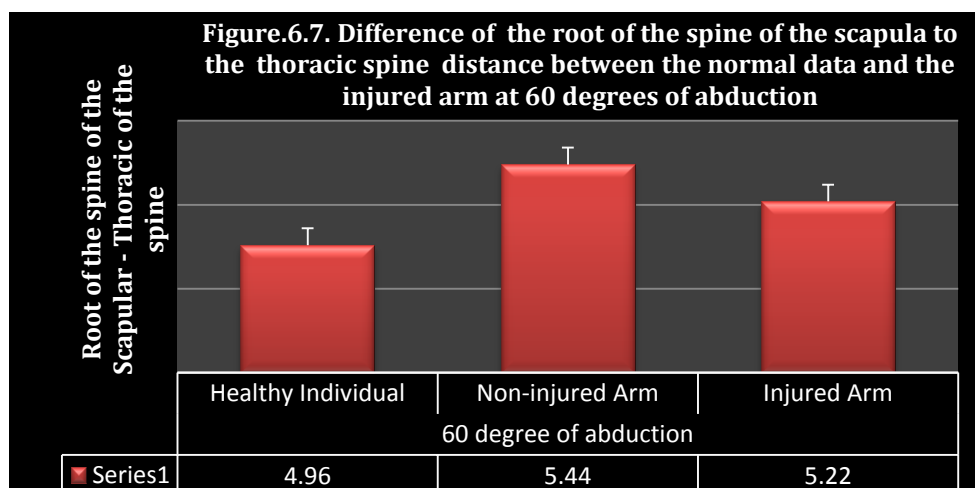
6.4.2.2.2 The distance between the root of the spine of the scapula and the thoracic spine (RS-TS)

The average of RS-TS distance for the healthy group is 4.96 with (± 0.526 SD) cm, which is lower than the patients with SAIS (See Table 6.8). The injured arm and non-injured arm groups showed similar averages, which were 5.44 (± 0.715 SD) cm and 5.22 (± 0.622 SD) cm, respectively (see Figure 6.7). The independent sample t-test did not find any significant difference between the healthy and non-injured groups ($t=1.84$, $p=0.074$), or between the healthy and injured groups ($t=1.05$, $p=0.302$). Furthermore, the paired t-test confirmed that the RS-TS distance resulting from the non-injured and injured groups is statistically not significant ($t=0.57$, $p=0.599$).

Table 6.8: Mean, with standard deviation (SD) values and the difference of the root of the spine of the scapula to the thoracic spine distance between the normal data group and the injured arm group at 60 degrees of abduction

Groups	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Healthy arm	4.96	$\pm .526$	4.00	5.97
Non-injured arm	5.44	$\pm .715$	4.60	5.97
Injured arm	5.22	$\pm .622$	4.30	5.83
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	.48		-1.84	.074
Healthy – Injured arm	.26		-1.05	.302
*Non-injured – injured arm	.22		0.57	.599

* Paired t-test is used to compare non-injured and injured arm.



6.4.2.2.3 The distance between the inferior angle of the scapular and thoracic spine (IN-TS)

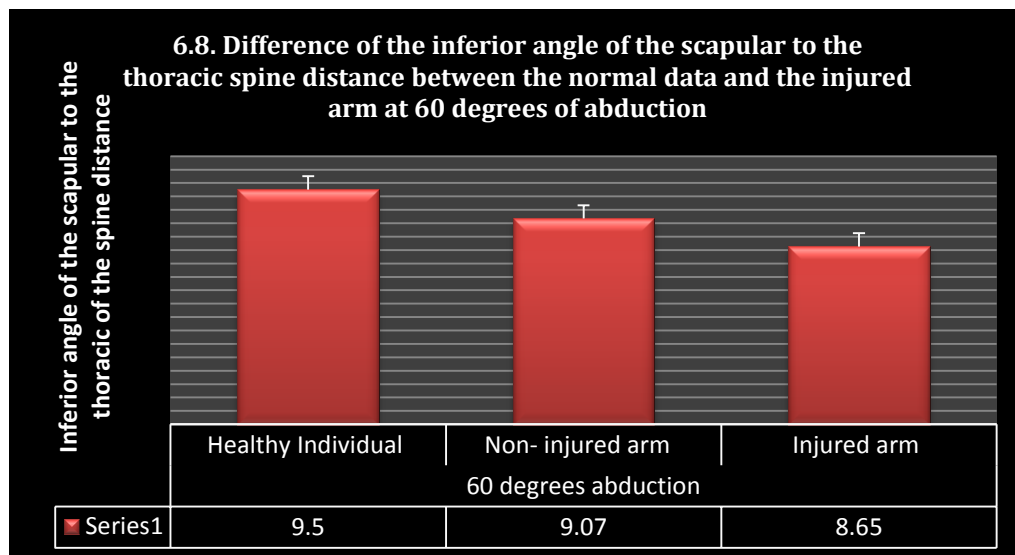
For IN-TS distance, it seems somewhat different among the three groups (see Figure 6.8). The IN-TS distance for the healthy group is 9.50 (± 0.962 SD) cm, which is the highest average (see Table 6.9).

The non-injured arm group revealed a very close average to the healthy individuals group with 9.07 (± 1.69 SD). While the injured arm group exhibited a lower average in IN-TS distance with 8.65 (± 1.18 SD) cm. The independent t-test confirmed that the healthy group was not different from the non-injured group, ($t=0.86$, $p=0.395$) or the injured arm group ($t=1.71$, $p=0.094$).

The paired t-test also showed no difference between the non-injured and injured arm groups ($t=0.97$, $p=0.407$).

Table 6.9: Mean, with standard deviation (SD) values and the difference of the inferior angle of scapular to thoracic spine distance between the normal data group and the injured arm group at 60 degrees of abduction				
Groups	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Healthy arm	9.50	± 0.962	8.10	12.40
Non-injured arm	9.07	± 1.69	6.43	10.70
Injured arm	8.65	± 1.18	6.59	9.47
Group Comparison	Mean differences between subgroup		t	p-value
Healthy - non-injured arm	0.43		0.86	.395
Healthy - Injured arm	0.81		1.71	.094
<i>*Non-injured - injured arm</i>	<i>0.42</i>		<i>0.97</i>	<i>.407</i>

** Paired t-test is used to compare non-injured and injured arm.*



6.5. Discussion

The aim of this chapter was to assess if the measurement tools used could detected differences in the SURA and AHD in patients with SAIS compared to the asymptomatic control group.

The differences in measuring the AHD and SURA were considered in light of the SDD in neutral and at 60 degrees of abduction, which was previously reported. Therefore it was expected that the differences between normal data and patients with SAIS would be seen in their measurements. Overall, this study hypothesis was supported and the current study tools detected differences between patients with SAIS and normal data at 60 degrees of passive abduction.

6.5.1 The acromiohumeral distance

6.5.1.1 The acromiohumeral distance in neutral position

The method has the SDD= 0.75 and 0.78 mm for the dominant and non-dominant arms in neutral position, the differences in AHD measured by RTUS in neutral position between normative data (healthy individuals - non-injured arm) and those with injured

arm revealed that there is no systematic significant difference between the three groups. The average value of the absolute difference was consistently less than the SDD ranging from 0.08 - 0.01 mm.

6.5.1.2 The acromiohumeral distance at 60 degrees of abduction

The method has the SDD= 0.67 mm for both arms at 60 degrees of abduction. In detecting the differences between patients with SAIS and normal data at 60 degrees of passive abduction the result indicated that the differences between the healthy individual and non-injured arm is reached at 0.34 mm therefore there is no significant difference between the two groups of normal data. While the differences between healthy individuals and patients with injured arms reached 1.68 mm with ($p= 0.003$), and non-injured arm and injured arm reached 2.02 mm with ($p= 0.001$) which subsequently explained the SDD indicating there was a significant difference in AHD between the normal data (healthy individuals - non injured arm groups) and the injured arm group at 60 degrees of abduction. Furthermore, these differences were above the SEM and the SDD values, therefore did not count due to measurement error, the AHD at 60 degrees of abduction measurements is significantly lower for the injured arm than normal data. This result supports the previous studies (Pijls et al., 2010; Desmuelles et al., 2004) that have shown an AHD average at 60 degrees decreased in patients with SAIS more than the healthy individual.

6.5.2 Scapular position

The differences between the injured arm in patients with SAIS and normal data when measuring the scapular position by using the PALM in neutral, the method has the SDD in average of SURA of 1.14 - 1.37 degrees, 0.37 - 0.60 cm for the RS-TS and

0.61 - 0.67 cm for IN-TS for both arms respectively and they were based on the reliability study.

6.5.2.1 Neutral position

6.5.2.1.1 Scapular upward rotation

The differences between the healthy individual and patients with SAIS in neutral position showed that the healthy individual group detected differences when compared to the other two groups (injured and non-injured arm groups). The differences for the non-injured and the injured arms were 2.23 -2.19 degrees respectively. This large difference was greater than the SDD that reported 1.37-1.14 degrees for both dominant and non-dominant arms while the differences between the non-injured and the injured arm indicated no significant differences. This would demonstrate that the scapula position in the injured arm group is similar on both sides which may indicate that the individual may have a bilateral anatomical-functional issue with scapular position, which could predispose them to impingement. This may in part provide some explanation for the likelihood of these similarities.

6.5.2.1.2 The distance between the root of the spine of the scapula and the thoracic spine (RS-TS)

The injured arm exhibited greater scores in the RS-TS distance when compared to mean scores of normal data, however, no significant differences were found between the normal data and the injured arm, the method has SDD of 0.37 and 0.60 cm for the dominant and non- dominant arms and the differences of RS-TS distance between the healthy individual and the two other groups exhibited lower than the SDD which detected there was a difference but it was not significant.

6.5.2.1.3 The distance between the inferior angle of the scapular and thoracic spine IN-TS

Likewise, comparison of the mean differences value of the IN-TS distance between the normal data (healthy group and non-injured arm) and injured arm in patients with SAIS detected significant differences with a mean value of 0.80 - 0.70 cm, and reported slightly higher than the SDD values 0.61- 0.67 cm, indicating that they are outside the parameters of measurement error therefore were not counted due to measurement error and these differences were statically significant with $p= 0.011- 0.044$.

6.5.2.2 60 degrees of abduction

6.5.2.2.1 The scapular rotation angle at 60 degrees of abduction

The injured arm exhibited a decrease in scapular rotation angle when compared to mean scores of normal data. The differences between injured arm in patients with SAIS and normal data (healthy group and non- injured arm) in measuring SURA at 60 degrees of abduction, were 1.02 - 4.01 degrees this is greater than the SDD that reported 0.73 and 0.91degrees for the dominant and non-dominant arms suggesting there was a difference between the normal data and the injured arm group in the SURA at 60 degrees of abduction and the differences were statically significant with $p= 0.020 - 0.022$ respectively.

6.5.2.2.2 The distance between the root of the spine of the scapula and the thoracic spine (RS-TS)

The RS-TS distance for the injured arm in patients with SAIS is lower when compared to mean scores of normal data. The (RS-TS) distance demonstrated no significant difference between the normal data and the injured arm.

6.5.2.2.3 The distance between the inferior angle of the scapular and thoracic spine IN-TS

The differences between the normal data (healthy group - non injured arm group) and the injured arm group of the IN-TS distance were 0.81- 0.42 cm respectively, the differences between the healthy individual group and the injured arm group was beyond the SDD that reported 0.37 and 0.58 cm for the dominant and non-dominant arms, there was a difference in the mean values of the IN- TS distance and it was greater than the SEM and the SDD values, but not significant with $p= 0.094$. The mean difference between the non-injured group and the injured arm group were not outside the SDD with $p= 0.407$. These differences were above the reported SEM values, and they were outside measurement error and may not contribute due to the measurement error but the p value result demonstrated no significant difference in the mean value of the IN- TS distance between the normal data and injured arm at 60 degrees of abduction.

Overall, the injured shoulders in this study exhibited lower scores in the SURA test at 60 degrees of passive abduction than the mean scores of normal data. These differences between the normal data and the injured arm group mean scores were greater than the SDD values taken from a previous reliability study on a similar population and they were highly significant but could not be contributed due to measurement error.

The measure of the injured shoulders in the current study had decreases in SURA and AHD; this suggests that the decrease in SURA may result in increased risk of SAIS injury. In addition, correlations between the AHD and the SURA were found in Chapter 5. Therefore, a decrease in SURA would appear to result in lower AHD, which

further supports the potential for SURA to be used as a screening tool for SAIS injury risk where the use of AHD analysis is not practical.

The findings of this study supported the hypothesis in that tests used by both the RTUS measures AHD and the PALM measures scapular position are sensitive to detect differences between patients with SAIS and normal data. One source of the limitations in this study which could have affected the measurements was that the numbers of participants with injuries were relatively small. Likewise it is noteworthy to realize that the AHD is also affected by other factors such as posterior tilt and external rotation.

6.6. Conclusion

The results of the current study have shown that the hypothesis concerning the test sensitivity to detect differences between patients with SAIS and normal data can be confirmed. Patients with SAIA, demonstrate trends of increased narrowing of the AHD when the arm is abducted passively to 60 degrees compared to the healthy control group. Further studies of AHD with active arm elevation in patients with SAIS are warranted to further determine different groups and different conditions in order to investigate whether or not these tests are sensitive. It is suggested that further prospective investigations of this potential are therefore reasonable.

Chapter Seven

7. The Intervention Programme

Conservative treatment of patients with subacromial impingement syndrome (SAIS) is often managed with multiple interventions including various treatment methods such as; strengthening and stretching exercises, manual therapy technique or both techniques, medication, electrotherapy techniques and tape (Linsell et al 2006; Desmeules, et al 2003; Green et al 2003; Celik et al 2009; Hsu et al 2008; Kalter et al., 2011; Miller & Osmotherly, 2009). The main aims of these interventions are to relieve pain, increase strength, reverse abnormal muscle imbalances, and restore pain-free joint range of motion (Green et al 2003).

A number of systematic reviews have been published to compare the effectiveness of the treatments on a variety of outcome measures, such as pain, range of movement, functional limitations and return to work for patients with SAIS. Some of these systematic reviews (Desmeules et al 2003; Hanchard et al 2004; Kuhn, 2009; Kelly et al 2010; Michener et al., 2004; Trampas & Kitsios, 2006; DeSouza et al., 2009; Kromer et al., 2009) have been published relating to the effectiveness of conservative modalities in general, they conclude that the effectiveness of various treatments is mainly based on the combination of these interventions, whereas other reviewers (Kuhn,2009; Kelly et al 2010; Kromer et al 2009), have addressed the exercise programme and these also showed significant weaknesses, moreover because they remain uncertain about the effectiveness of these programmes, also there is very little emphasis on which muscles have to be targeted, and which is the optimal strengthening approach (Hanratty et al., 2012).

Moreover, Desmeules, et al., 2003, Kuhn, 2009, Kachingwe, et al 2008, Michener, et al 2004 have argued that a combination of therapeutic exercises and manual therapy have a positive impact on patients with SAIS. However, there is limited evidence to support the efficacy of the therapeutic exercises and manual therapy to treat impingement syndrome (Desmeules, et al., 2003). Other studies by Schmitt (2001) and Speed (2002) found strong evidence that extracorporeal shock-wave therapy is no more effective than placebos (Schmitt, et al 2001, Speed, et al 2002).

In taping studies the researchers demonstrated that taping effectively improved the joint stability through a biomechanical realignment of the joints, increased the shoulder range of motion, and reduced pain and discomfort of the shoulder (Lewis, et al 2005; Bennell et al., 2000; Host, 1995; Whittingham, et al 2004). Another possible mechanism is that taping enhances the muscle force produced by altering the length-tension relationship of muscles (Host, 1995; Morrissey, 2000). However, the underlying mechanisms of the taping effects are still unclear; both Ackermann et al., (2002) and Alexander et al., (2003) believe that taping works by offering constant proprioceptive feedback or providing alignment correction during dynamic movements. Therefore, it is important to understand which technique will have the greatest impact for a particular condition type.

Normal upper limb functions are dependent on the ability to statically and dynamically position the shoulder girdle in an optimal coordinated fashion (Glousman 1988, Kibler 1998). Changes in scapular positioning and motor control are considered important risk factors for developing SAIS (Mottram, 1997; Cools et al., 2005; Endo et al., 2004; Hébert et al., 2002; Host, 1995;) amongst many others. The scapular movements are refined by the neuromuscular control of the muscles attaching to the scapular. Of all

these muscles, the Trapezius and Serratus anterior muscles are paired to form the important force couple which controls the movement of the scapular's upward rotation and posterior tilt (Hsu et al., 2009). These mechanisms of scapular movement are vital for widening the subacromial space to prevent the impingement of the subacromial tissues (Michener et al., 2003; Solem-Bertoft et al., 1993).

A present study by Atalar et al. (2009) suggests that reducing scapular mobility will lead to decrease the AHD during arm abduction and subsequently increases the risk for SAIS. Alterations in scapular motion have been linked to decreases in Serratus anterior muscle activity, increases in upper Trapezius muscle activity, or an imbalance of forces between the upper and lower parts of the Trapezius muscle (Kamkar et al., 1993). This may adversely affect the scapular positioning, including reduced scapular upward rotation, increased anterior tilt and scapular winging (Cools et al., 2005; Ludewig and Cook, 2000, Borstad & Ludwig, 2005). Therefore, when developing rehabilitation strategies to prevent and treat patient with SAIS it will be necessary to deal with the scapular motion, which appears to be important during glenohumeral elevation.

A number of studies in the literature (Ackermann, Adams, & Marshall, 2002; Alexander, Stynes, & Thomas, 2003; Selkowitz et al., 2007; Thelen et al., 2008) amongst others have presented the taping application techniques which are frequently used in clinical practice to improve symptoms through a correction of the scapular position at rest and during motion and to investigate whether tape can facilitate or inhibit activity within the scapular rotators (Lewis et al., 2005; Smith et al 2009). Despite the popular and practical success of this practice, little research has appeared in the literature to determine taping application effects on the AHD. In a review of the literature, only one article investigating the effects of taping on AHD was performed

by (Luque-Suarez et al., 2013) who investigated the effectiveness of kinesiotaping (KT) on the acromiohumeral distance (AHD) in asymptomatic subjects for a short period. The result showed increases in the AHD immediately following kinesiotaping application in healthy individuals.

In general, there is a lack of information and research about the effectiveness of these taping techniques on the AHD outcome measures through the manipulation of the scapular position. Therefore, this chapter will focus first on the effect of the tape application on AHD through the manipulation of the scapular position. The rationale for using taping is to normalise the scapula humeral rhythm by altering the scapular muscle activity and correcting the abnormal scapular position; this may provide improvement in the AHD. This chapter also will focus on the effect of the muscle stimulation on AHD. There are a number of studies that emphasise the role of scapular muscle training as an essential component of shoulder rehabilitation (Cools et al., 2007; Cools et al., 2003). The intervention proposed in this study includes taping, targeting and contracting muscles for specific impairments as described in patients with SAIS.

The objective of this chapter:

- 1- Investigate the effectiveness of changing the scapular position by (taping) on AHD and SURA.
- 2- Investigate the effectiveness of muscle stimulation of Serratus anterior and lower fibres of Trapezius on the AHD by using NMES electronic muscle stimulator.

7.1. Influence of changing scapular position on acromiohumeral distance by using tape.

7.1.1 Introduction

Assessment and treatment of the scapular motion have become fundamental components of shoulder rehabilitation (De Mey et al., 2012; Kibler et al., 2012, Taylor, et al., 2005). As such, the scapula acts as a transfer link for developed forces in the kinetic chain as well as a stable base for optimal muscle activation (Kibler et al., 2009). Normal muscle activity of the scapular rotators allows for the normal kinematics of the scapular movement (Cools et al., 2002), and is believed to be critical to preserving the subacromial space and preventing impingement during arm elevation (Phadke et al., 2009).

Altered scapular kinematics are assumed to reduce the SAS creating inadequate space for clearance of the rotator cuff tendons and other subacromial structures as the arm is elevated (Graichen et al., 2008). Imbalance activation of muscle performance that stabilises the scapula may alter scapular kinematics, for instance, increased upper Trapezius activity, and delayed lower Trapezius activity production of impingement symptoms due to loss of acromial elevation and posterior tilt (Smith et al., 2002; Ludewig & Reynolds, 2009; Ludewig & Cook 2000), also decreased Serratus anterior activity potentially reducing scapular external rotation and upward rotation with arm elevation (Cools et al., 2003).

URA of the scapular is assumed to be one of the factors related to subacromial impingement and narrowing of the subacromial space (Forthomme et al., 2008). Due to Serratus anterior muscle activity it is vital to prevent the humeral head from impinging on the acromion during arm elevation and excessive winging or anterior tilting leads to a relative decrease in the subacromial space (Kamkar et al., 1993).

SAS is considered as an essential portion of the normal shoulder function and it can be evaluated by measuring the AHD, (Luque-Suarez et al 2013), this is a two-dimensional linear measure of the smallest distance between the under surface of the acromion and the most anterior part of the humerus (White et al., 2012; Hebert et al., 2003; Desmeules et al., 2004). Narrowing this distance has been associated with SAIS. Hebert et al., 2003; Desmeules et al., 2004; Mayerhoefer et al., 2009; Matsuki et al., 2012 amongst others; have suggested that the upward rotation of the scapula is clinically important because the scapula must rotate adequately in an upward fashion to prevent the humeral head from compressing and shearing against the under-surface of the acromion process during humeral elevation (Ludewig, 2000, Johnson, 2001). Therefore, when developing rehabilitation strategies to prevent and treat patient with SAIS it will be necessary to deal with the scapular motion, which appears to be important during glenohumeral elevation.

The muscular control of the scapula has become a recent focus of therapeutic intervention. In recent times, taping the scapula has been suggested as a method of improving both the scapula position and muscular efficiency of the shoulder girdle (Ackermann et al., 2002), various taping procedures of the scapula have been introduced into the conservative management of the shoulder girdle (Host 1995; Mottram 1997; Schmitt & Snyder-Mackler, 1999), these techniques are frequently used in the management of shoulder pain and as a part of injury prevention strategies. It is believed to alter scapular kinematics and help reduce pain and restore normal function (Shaheen et al., 2012; Lewis et al., 2005; Thelen et al., 2008). It increases joint stability via a biomechanical realignment of the joints (Bennell et al., 2000, Host 1995, Shaheen, 2012) and it acts as a restriction to the joint range (Bradley et al., 2009, McConnell et al., 2011) and speed (Wilkerson, 2002) and range of motion.

Previous studies have documented the influence of the scapular position provided by tape, and these are aiming to correct the abnormal scapular position and influencing the muscle activity of the scapular, however, there is little information on how the scapular position realignment by tape can influence the AHD. Therefore, it is important to establish normal values that may be used to assess the effects of tape in symptomatic subjects. The main contribution of this study is to propose a taping technique to investigate the effectiveness of modifying the scapular position on acromiohumeral distance in healthy individuals, the rationale for using taping is to normalize the scapula-humeral rhythm by altering the scapular muscle activity and correcting abnormal scapular position. This may provide improvement in shoulder disability and pain.

7.1.1.1 The objective of the study

- 1- Investigate the effectiveness of changing the scapular position (taping) on AHD.
- 2- Investigate the effectiveness of changing the scapular position (taping) on SURA.

7.1.1.2. Null hypothesis

- There is no effect of changing the scapular position on AHD and SURA by applying tape on the upper trapezius (UT) muscle.
- There is no effect of changing the scapular position on AHD and SURA by applying tape on the serratus anterior (SA) muscle.
- There is no effect of changing the scapular position on AHD and SURA by applying tape on both the upper trapezius and serratus anterior (UT&SA) muscles.

7.1.1.3 Alternative hypothesis

- The effect of changing scapular position on AHD and SURA by applying tape on the upper Trapezius (UT) muscle will be positive that is distance and angle respectively will increase.
- The effect of changing scapular position on AHD and SURA by applying tape on the Serratus anterior (SA) muscle will be positive that is distance and angle respectively will increase.
- There is an effect of changing the scapular position on AHD and SURA by applying tape in both the upper Trapezius and Serratus anterior (UT&SA) muscles will be positive that is distance and angle respectively will increase.

7.1.2 Method and Material

7.1.2.1 Study design

A one-group pre-test/post-test repeated measures design used to compare the effects of taping application on AHD and SURA in healthy individuals.

7.1.2.2 Participants

A power analysis was carried out using G Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), with an effect size of 0.5, a significance level of 0.05, and a statistical power of 0.8, the required sample size was calculated to be sixteen participants. The right shoulder of twenty participants (ten males - ten females) with mean age 26.95 (± 8.03 SD) were recruited from the student population of the Health, Sports and Rehabilitation Sciences programmes at Salford University. The included participants needed to meet the following criteria: a) no shoulder pain in the previous month prior to participation, b) between 18 and 50 years of age, c) no history of pain or movement limitation to the shoulder.

Exclusion criteria were as follows: Subjects who had any shoulder surgery or clinical treatments for a shoulder injury.

7.1.2.2.1 Ethical approval

Approval for this study was received from the Institutional Review Board at the host University, in accordance with the latest revision of the Declaration of Helsinki (2008). All participants signed the written informed consent form prior to their participation in this study.

7.1.2.3 Procedure

Participants had tape applied in the traditional fashion on three groups of muscles from anterior to posterior. Group 1 - upper Trapezius muscle (UT); Group 2- Serratus anterior muscle (SA); Group 3- combining both muscles (UT & SA). All participants received the tape application after the initial examination by the investigator. RTUS measures of AHD were taken before and after the initial tape application, at 60 degrees of passive shoulder elevation in the scapular plane.

7.1.2.3.1 Taping techniques

All taping techniques were applied by another investigator who had more than 15 years' experience in musculoskeletal disorders. First, the skin of the dominant shoulder was prepared with alcohol to assist adherence of the tape. Second, standard 5 cm Hypafix tape was used as the underlayer before applying the 3.75 cm rigid zinc oxide tape (Morrissey 2000; Macdonald 2009).

The UT group 1: received tape application to compress the UT muscle belly and reduce activity in order to increase AHD. While the participants were in an upright standing position the investigator applied a Hypafix tape without any tension with the

arm at rest by the side in a support position, starting at the anterior shoulder below the coracoid and over the muscle belly of the UT (mid clavicle), with the border of the tape adjacent to the angle of the neck (Figure.7.1.1) attaching on the posterior area as far down as thoracic spine (T9/10), following the muscle fibres of the lower Trapezius. Then, the rigid tape was applied with minimal tension from just above the clavicle, the initial pull on the tape was upward and then back as the tape came over the midline, and the tail of the tape was attached as far down as possible (T9/10) (Morrissey 2000; Macdonald 2009).



Figure.7.1.1. Rigid Tape, applied on the upper trapezius UT with minimal tension from just above the clavicle, the initial pull back and forward as the tape comes over the midline. And the tail of the tape attached as far down possible (T9/10).

Group 2; SA: received tape application treatment to facilitate the action of the SA muscle to upwardly rotate the scapular during shoulder elevation in order to increase AHD, While the participants were standing, the investigator applied a Hypafix tape without any tension with arm abducted, from 2 cm medial to the scapula border, over the inferior angle of the scapular following the line of the ribs down around the chest wall to the mid-axillary line. Then, the same procedure was repeated with a rigid tape on the Hypafix tape with minimal tension, the tape pulled posteriorly round the chest (Figure.7.1.2).

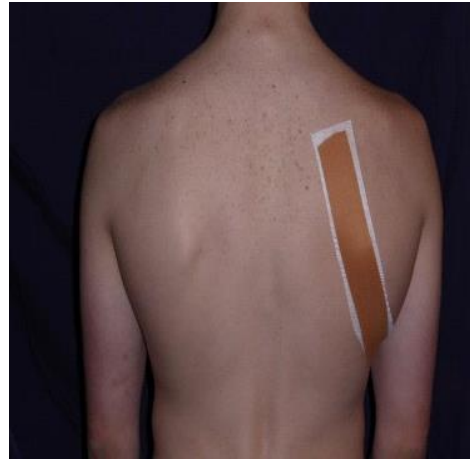
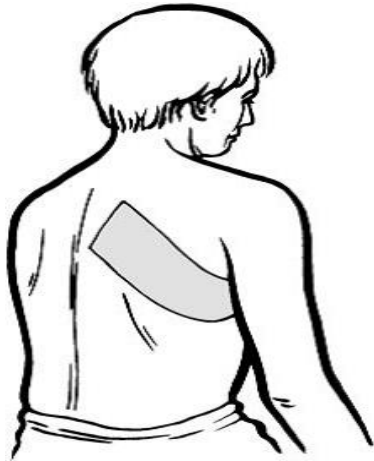


Figure .7.1.2. Tape applied on the Serratus Anterior muscle (SA), over the inferior angle of the scapular following the line of the ribs down around the chest wall to the mid-axillary line.

Group 3: muscles received the taping technique that was mentioned above combining both UT & SA muscles. The same procedure was repeated, the strip was applied in the same place as UT and SA, with the shoulder in neutral (Figure. 7.1.3). In all groups, after the outcome data were collected, the tape was removed by the physiotherapist.



Figure.7.1.3. Rigid tape applied on combination both (SA) & (UT).

7.1.2.3.2. Ultrasound measurements

The RTUS of the shoulder was performed by one investigator using Mylab 60 Esaote, Xvisoin model, with a 523 linear transducer and the frequency of the image set at 13 MHz linear transducer. Afterwards, the first investigator applied the tape over the three groups of muscles, UT, SA, and the combined both UT&SA respectively the participant was asked to sit against the short back rest of the chair, sit up straight, pull their shoulders back and look straight ahead. The participants' hip and knees were flexed at 90 degrees, and feet rested flat on the floor. And the arm was passively placed at 60 degrees of abduction in the scapular plane, on precut 60 degrees wedges the 60 degrees of elevation was chosen because the AHD is smallest between 60 and 120. A goniometer was used to ensure the correct position of the arm at 60 degrees of abduction.

The ultrasound transducer was placed on the lateral aspect of the acromion in line with the longitudinal axis of the humerus to visualise both the humerus and acromion. On the images, the AHD was measured vertically; measurements were taken from the lateral edge of the acromion process of the scapula to the nearest margin of the humerus, with the arm at 60 degrees of passive abduction position.

Image capture was taken on the same day, three consecutive ultrasound images were captured at 60 degrees of passive abduction position, and measurements were done on two occasions: Pre-post measurements on effect of the tape intervention - on each muscle group, resulting in twelve images per participant. All ultrasound images were frozen on the screen and saved onto an external hard drive from the ultrasound scanner and stored for offline analysis using Image J software. A time interval of 5 minutes was provided between each group of muscles measurement. The whole process was

repeated two more times resulting in twelve images of each sitting test condition: UT, SA and combining both UT with SA muscle groups.

7.1.2.3.3 Palpation meter measurements

SURA was also calculated, the horizontal distance between the scapula and the thoracic spine was measured by using the PALM. PALM measurement of the scapular position and rotation was measured for each participant. Anatomical landmarks on the subjects' scapula and thoracic spine were identified by palpation before the trial started. Subjects stood with their feet comfortable, with their arm abducted at 60 degrees of passive abduction, this position was maintained throughout the testing procedures for the three muscle groups, and distance was measured on the same day, a value of the three measurements was recorded three times. Measurements were done on two occasions: Pre-post measurements on the effect of tape intervention - on each muscle group, a time interval of 5 minutes was provided between each group measurement. The whole process was repeated two additional times of each sitting test condition: UT, SA with both UT with SA group muscles.

Calculation of the scapular rotation was performed by using the distance between the root of the scapula and the closest horizontal spinous process (TS_RS), the distance between the thoracic spine and the inferior angle of the scapula (TS_IN), and the distance between the root of the scapula to the inferior angle of the scapular (RS - IN).

7.1.3. Data analysis

Kolmogorov-Smirnov test was utilized to assess the normality of distribution for testing such variables (AHD and SURA) before intervention. Normal distribution was observed for both variables.

Intra-rater and inter-rater reliability of measuring the AHD by using RTUS and SURA by using the PALM was established by calculating the ICC and SEM for using a two-way mixed effect.

Pair t test was used to identify the differences between Pre- and post- ultrasound measurement of AHD for the three groups tested in control and experimental groups. A repeated measures ANOVA was used to detect between-group differences; post-hoc test is used to compare each pairs of muscles group for multiple comparisons. The data were analysed using SPSS version 20. A p value of <0.05 was considered statistically significant.

7.1.4. Results

This study focuses on: i): the difference in AHD before and after using tape application. ii): the difference in SURA before and after using tape application.

7.1.4.1. Acromiohumeral distance

To find the effect of the group muscles; Group 1- UT muscle, Group 2- SA muscle and Group-3 combined both SA& UT muscles, on AHD by using tape. Pre- and post-ultrasound measurement of AHD was used for the three groups of muscles tested in control and experimental groups and is presented in Table.7.1.1.

The AHD increased significantly for the three types of muscle groups after tape application. No significant differences were found in the AHD between the three groups of muscle at baseline measure. However, there was a significant difference in AHD after using tape for the three muscle groups. Table 7.1.1 depicted the summary statistics and the paired t-test.

Table 7.1.1: Paired t-test of Acromiohumeral distance measurement for pre/post-tape

Muscles group	Pre				Post				t	p-value
	Mean (mm)	SD (mm)	Min	Max	Mean (mm)	SD (mm)	Min	Max		
Upper trapezius (UT)	9.18	1.38	5.63	11.12	9.56	1.49	5.61	11.87	-3.89	.001
Serratus anterior (SA)	8.98	1.52	5.75	11.08	9.78	1.53	6.95	12.60	-7.67	<.001
Combined both muscles (UT&SA)	9.02	1.45	5.32	11.89	9.92	1.64	6.32	12.95	-5.09	<.001

Group 1: The UT muscle group, the average of AHD before using the tape is 9.18 mm with (± 1.38 SD) mm, whereas after using the tape it becomes somewhat higher, 9.56 mm with (± 1.49 SD) mm, and there is a highly significant increase in the AHD ($t = -3.89$, $p\text{-value} = 0.001$), see Figure 7.1.4 for the effect of Upper Trapezius (UT) muscle by using Tape on the acromiohumeral distance.

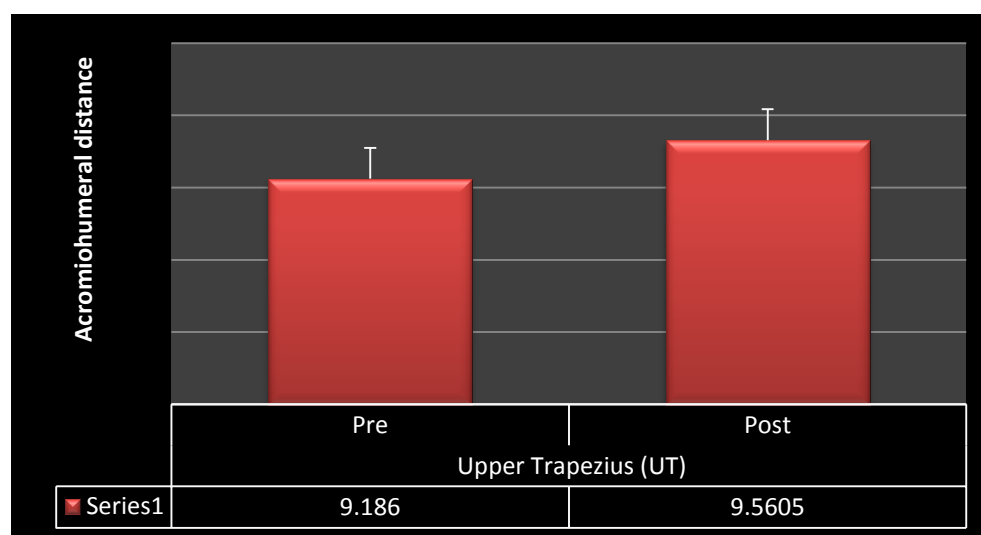


Figure 7.1.4:

The effect of Upper Trapezius (UT) muscle by using Tape on the acromiohumeral distance.

Group 2: the SA muscle group: The mean of the AHD before using the tape, is 8.98 mm with (± 1.52 SD) mm this appears to be smaller than after using the tape, which is 9.78 mm with (± 1.53 SD) mm, the paired t-test shows the increase in the distance is

very highly significant ($t=-7.67$, $p\text{-value}<0.001$). See Figure 7.1.5 the effect of Serratus Anterior (SA) muscle by using Tape on the acromiohumeral distance.

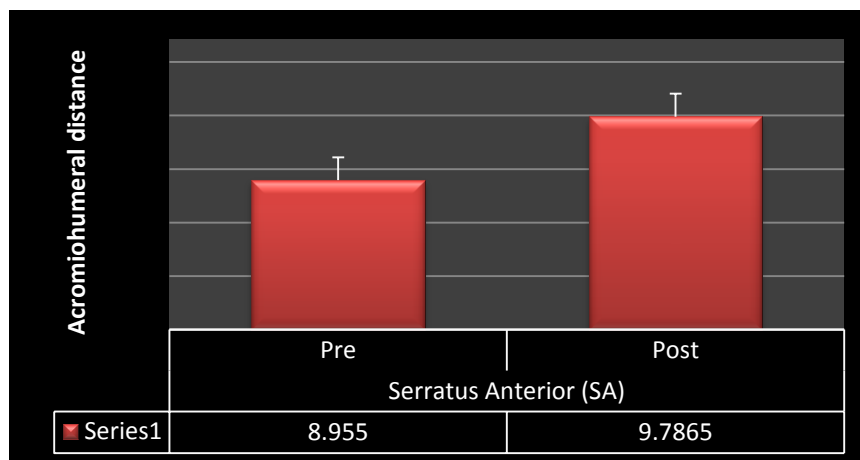


Figure.7.1.5. the effect of Serratus Anterior (SA) muscle by using Tape on the acromiohumeral distance.

Group 3: combines both muscles the UT & SA, similar to the mentioned results, the mean of the AHD before using the tape for combining both UT&SA muscles is 9.02 mm with (± 1.45 SD) mm, and is smaller than the average after using the tape is 9.92 mm with (± 1.64 SD) mm, the paired t-test confirmed that the difference is, statistically, very highly significant ($t=-5.9$, $p\text{-value}<0.001$). See: Figure 7.1.6 that shows the effect of combining both (UT & SA) muscles by using Tape on the acromiohumeral distance.

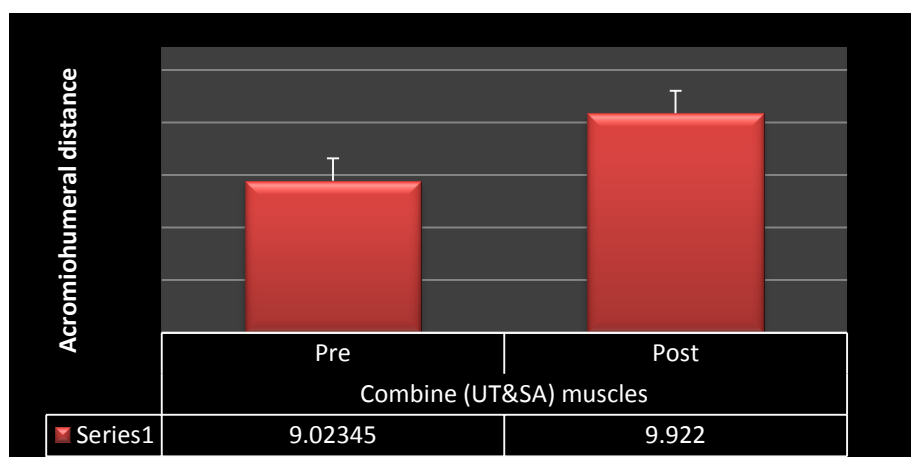


Figure 7.1.6 the effect of combining both (UT & SA) muscles by using Tape on the acromiohumeral distance

For, the differences between the three group muscles for AHD measurement: first for each group it is necessary to construct a new variable representing an increase in the AHD by finding the difference between the after and before use of the tape. Then, repeated measures analysis was used to find the statistical significant differences.

The UT muscle group shows the lowest increase in the AHD which is 0.375, whereas SA and combined UT&SA muscle groups show a close to a mean increase which are 0.803 and 0.890, respectively, see Figure 7.1.7.

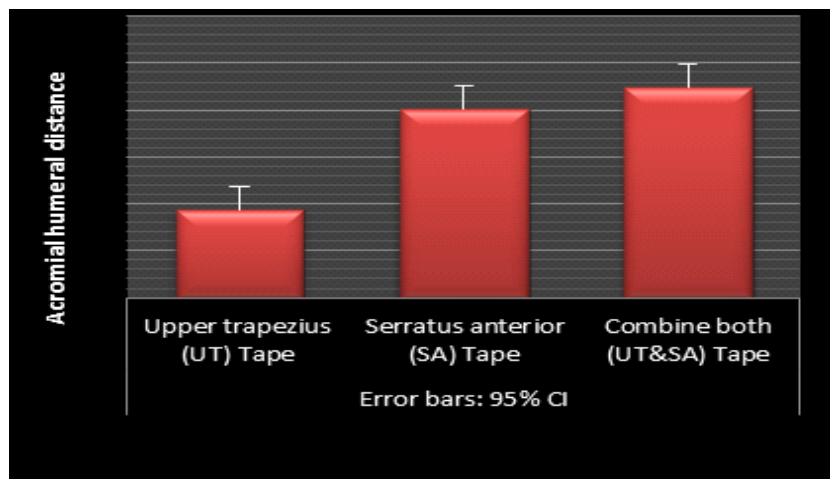


Figure.7.1.7. the differences of acromiohumeral distance between the three groups of muscles after using Tape.

From the figure, the 95% CI of mean increase is somewhat wider for the UT & SA group than the remaining groups. From the table 7.1.2, the Mauchly's test of sphericity is found to be significant (chi-square= 7.723, p-value= 0.021), and hence, the ANOVA test will be based on Greenhouse Geisser statistics. For the repeated measures ANOVA test is significant (Greenhouse Geisser= 3.098, p-value= 0.016), the difference in increase AHD between the three groups is statistically significant.

Table 7.1.2: Repeated measures ANOVA using Greenhouse Geisser statistics				
Muscles group	Mean difference between pre/post	Greenhouse Geisser	d.f	p-value
Upper trapezius (UT)	.375	3.098	1.483	.016
Serratus anterior (SA)	.803			
Combined both muscles (UT&SA)	.896			

Mauchly's Test of Sphericity: chi-square=7.723, p-value=.021.

As the difference is significant, the post-hoc test was used to compare each pair of muscle using the paired t-test. After adjusting the p-value, the significant difference is due to the difference between UT muscle and SA muscle group ($t=-2.989$, $p\text{-value}=0.008$). Statistically, the difference in AHD increase between SA and UT&SA is not significant ($t=-.688$, $p\text{-value}=0.500$). Although the increase in the UT muscle group is noted to be lower than the combined muscle group UT&SA, the t-test is not significant ($t=-2.46$, $p\text{-value}=0.024$) compared with 0.016 level of significance. Table 7.1.3: provides Paired t-test for comparing the pairs of the AHD between the three groups of muscles.

Table 7.1.3: Paired t-test for comparing the pairs of the acromiohumeral distance between the three groups of muscles			
	UT-SA	UT - (UT&SA)	SA - (UT&SA)
t-test	-2.989	-2.46	-.688
p-value	.008	.024	.500

The question as to whether there is an increase in the AHD after using the tape for the three types of muscle group is shown in these results: The percentage of increase AHD is found to be higher for SA muscle group, which is 95%, and then it is followed by

combining both UT&SA muscles which, is 90%, however, in the UT muscle group, the improvement is observed in 75% of the participants. Table 7.1.4 shows the percentages of those who show an increase in AHD.

Table 7.1.4: Result for the number of participants who showed an improvement in acromiohumeral distance measurement after using the tape.

Muscles group	Improvement		No improvement	
	Number	%	Number	%
Upper trapezius (UT)	15	75	5	25
Serratus anterior (SA)	19	95	1	5
Combined both muscles (UT&SA)	18	90	2	10

7.1.4.2. Scapular upward rotation angle

SURA has increased significantly for the three types of muscle group after tape application. All data are presented in Table 7.1.5. provide a descriptive data of the mean and standard deviation and the paired t-test.

Table 7.1.5. Paired t-test of scapular upward rotation angle measurement for pre/post- tape

Muscles group	Pre				Post				t	p-value
	Mean (mm)	SD (mm)	Min	Max	Mean (mm)	SD (mm)	Min	Max		
Upper trapezius (UT)	11.23	2.46	7.46	14.12	12.14	2.43	8.34	18.65	-1.38	.183
Serratus anterior (SA)	12.04	2.48	8.15	13.03	13.04	2.09	9.46	17.70	-1.99	.062
Combined both muscles (UT&SA)	11.98	2.60	7.46	12.47	12.47	2.47	7.80	18.14	-.97	.345

Measurements of the SURA for the UT muscle group before using the tape is 11.23 degrees with (± 2.64 SD) degrees which seems to be smaller than the average after using the tape where the average increases are 12.14 degrees with (± 2.43 SD) degrees.

Using the paired t-test, no significant difference ($t=-1.38$, $p\text{-value}= 0.183$) in pre/post for SURA measurement. Figure 7.1.8 shows the effect of UT muscle taping on the scapular upward rotation angle.

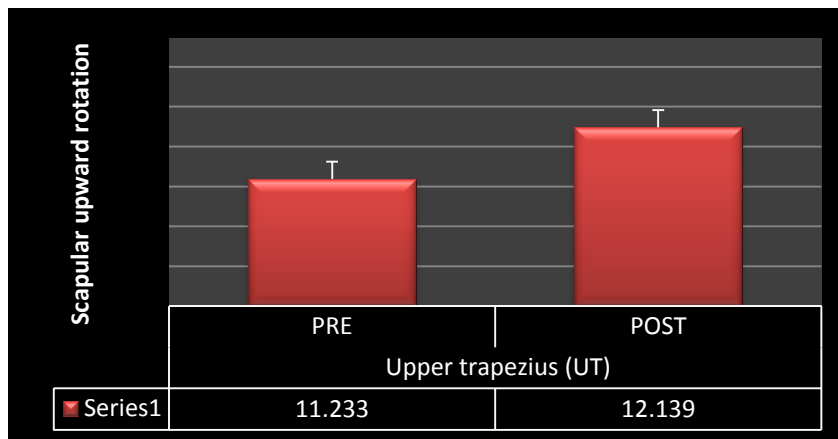


Figure 7.1.8 the effect

of Upper Trapezius (UT) muscle taping on the scapular upward rotation angle.

Regarding the SA muscle group, the average of SURA pre measure is 12.04 degrees with (± 2.84 SD) degrees which, is lower than the SURA post measure which is 13.9 degrees with (± 2.09 SD) degrees, Although there is an increase in the mean difference, between the pre and the post measure, this improvement is not significant ($t=-1.99$, $p\text{-value}= 0.062$). See Figure 7.1.9.

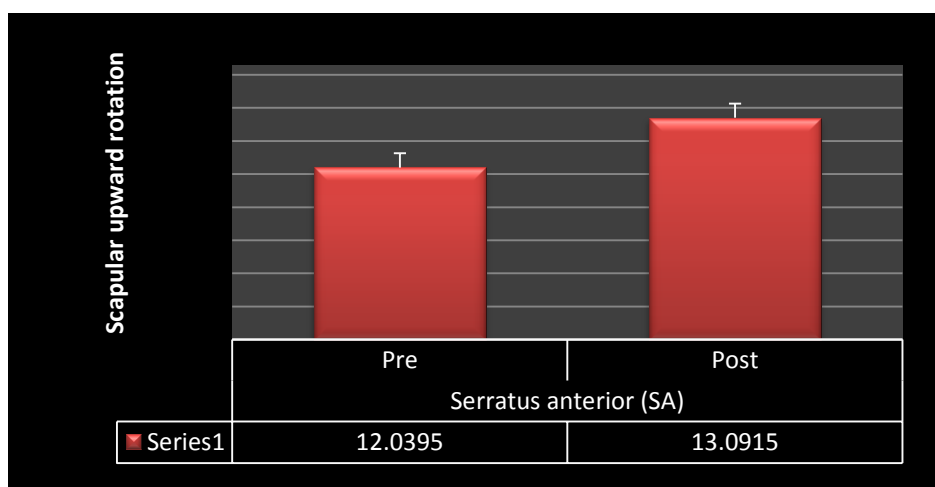


Figure.7.1.9.

the effect of Serratus Anterior (SA) muscle taping on the scapular upward rotation angle.

Likewise, for the combination of both groups of muscle UT&SA, there is an increase in SURA average after using the tape, where the average is 11.98 degrees with (± 2.60 SD) degrees for pre measurement, while for post measurements is 12.47 degrees with (± 2.47 SD) degrees measurements, however, the t-test shows the observed differences is statistically not significant ($t = -.97$, $p\text{-value} = 0.345$). See Figure 7.1.10.

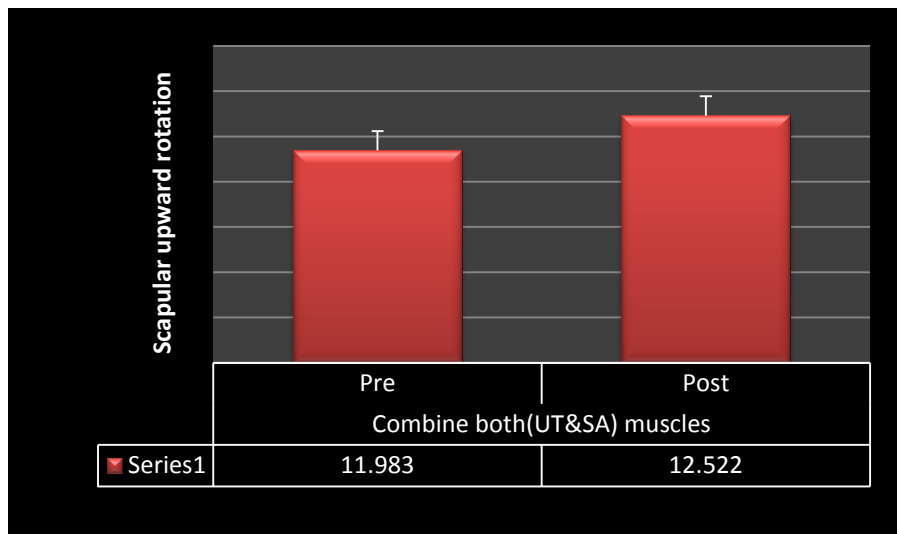


Figure 7.1.10:

The effect of combining both Upper Trapezius & Serratus Anterior (UT &SA) muscles taping on the scapular upward rotation angle.

The average of the difference between pre and post measurement of SURA for each group of muscle is presented in Table 7.1.6. The lowest improvement, which is 0.539, is observed with combining both the UT&SA muscle, whereas UT and SA show very close averages, which are 0.996 and 0.906, respectively.

Table 7.1.6: Repeated measures ANOVA using sphericity			
Muscles group	Mean difference between pre/post	F	p-value
Upper trapezius (UT)	.906	2.794	.245
Serratus anterior (SA)	.996		
Combined both muscles (UT&SA)	.490		

Mauchly's Test of Sphericity: $\chi^2 = 1.438$, $p\text{-value} = .487$

Using the repeated measures ANOVA, Mauchly's test of sphericity is not significant (chi-square=1.438, p-value= 0.487), and hence the ANOVA test based on assuming sphericity is used. The test shows there is no significant difference ($F=2.79$, p-value= 0.245) between the three groups in terms of pre/post measurements. The 95% CI is very wide for the three groups of muscles, indicating that there is high variation in difference between pre/post measures for each muscle.

Table 7.1.7: Result for the number of participants who showed an improvement in the scapular upward rotation angle measurement after using the tape.

Muscles group	Improvement		No improvement	
	Number	%	Number	%
Upper trapezius (UT)	15	75	5	25
Serratus anterior (SA)	13	65	7	35
Combined both muscles (UT&SA)	11	55	9	45

The result in Table 7.1.7 depicts the improvement for SURA measurement. The highest percentage of improvement is found for UT taping which is 75%. Then, the improvement percentages which are 65% and 55% were observed in SA and UT&SA, respectively.

7.1.5 Discussion

The current study investigated the effect of changing the scapular position on the AHD and SURA after applying tape application in asymptomatic individuals.

The results illustrated that the AHD, measured by ultrasound, increased significantly after applying the taping in all three muscle groups. The results also showed that there is a significant difference in AHD measured between the three groups of muscles on the effect of tape application. For the SURA, measured by palpation meter, there was

an increase in the SURA after applying taping in all three muscle groups, on the other hand, no significant difference was found in SURA between the three groups of muscles after the application of tape.

It was hypothesised that the application of tape would result in increased AHD; Regarding Serratus anterior (SA); following the tape application the AHD increased in a number of the participants and the percentage of the participants who had an improvement in the AHD after taping the SA muscle was the highest percentage of 95%. Similarly, for combining both muscles UT&SA, the percentage of participants whose was enlarged in the AHD after using tape application was 90%. While for the UT muscle, after the tape application the percentage of the participants who had improvement in AHD was 75%.

The findings of the present study partially supported the hypothesis of this study, the AHD increased significantly in all three groups of muscle; UT and the SA and the combination of both of them after applying tape application. However, to ensure the experimental magnitude of the change in the AHD that attained by Tape application in this study is sufficient to consider real change. This should be considered in the light of the methodology reliability of the AHD measurement at 60 degrees abduction which was previously reported. The method has measurement error (0.24 mm) and smallest detectable difference (SDD= 0.67) which is considered true change.

On the one hand, the magnitude of change for the UT observed in the AHD at 60 degrees of abduction is small and it is possible that the difference is a result of a measurement error rather than a real change in AHD. Based on this finding it does not seem that taping the UT muscle that is part of this study is important. On the other hand, one of the more significant findings from this study is that the magnitudes of

change in the AHD at 60 degrees of abduction for the combination of both muscles UT&SA and the SA respectively exceeded both of the measurement method errors and the SDD; therefore suggesting a real change in the AHD which is not attributable to error.

A review of the literature reported that tape application techniques are frequently used in clinical practice to improve symptoms through a correction of the scapular position at rest and during motion (Lewis et al., 2005). However, most of these studies have only considered the effect of scapular taping on the electromyographic activity of surrounding muscles (Cools et al., 2002; Alexander et al., 2003; Ackermann et al., 2002; Selkowitz et al., 2007) and others. There are other studies that investigate the effect of taping on scapular kinematics (Host, 1995; Hsu et al., 2009, Shaheen., et al 20013). Nonetheless, there is inadequate information in the literature about the effect of manipulation of the scapular position by using tape on the AHD and SURA. Only one recent study by Luque-Suarez et al., 2013 that investigated the effect of kinesiotaping (KT) on AHD, the result showed KT have a positive effect on AHD when compared with sham taping in asymptomatic individuals. The results also suggested that there is no difference in the effect on the AHD if kinesiotape is applied in the anterior to posterior direction. The results of this study are partly consistent with the present study, however, the study did not differentiate the effect of the kinesiotape on the AHD when it was applied in a different direction and the authors did not investigate the effects of scapular position by using tape on SURA. While, this present study was designed to determine the effect of changing the scapular position on the AHD as well as SURA which demonstrated that the taping application can significantly increase the AHD.

When examining the effect of the tape application techniques on the scapular position, it was hypothesised that scapular taping would result in increased SURA. The SURA following the tape application of the UT, increased in 75% of the participants. Similarly, there was 65% of participants who had had an improvement of SURA after tape application of the SA muscle which was a lesser improvement than those with the UT 75%, but when combining both muscles LT&SA, there was 55% of the participants who had an improvement in SURA which was the lowest percentage.

It seems that the SURA increased in all the three groups of muscle; UT and the SA and the combination of both of them after applying the tape. However, to ensure that the experimental magnitude change of the SURA attained by using tape application in this study is sufficient to consider real change, this should be considered in light of the methodology reliability of the SURA measurement at 60 degrees abduction which was previously reported in chapter 4. The method has measurement error (0.33 mm) and the SDD= 0.91 which is considered true change. Although the magnitude of change for the SA was observed in the SURA at 60 degrees of abduction, exceeding both of the measurement method errors and the SDD, however it was not significant. While the magnitude of change for UT and combining both muscles UT &SA was not beyond the SDD therefore the change was not real and could be attributed to measurement error.

A number of studies have found that taping helps in restoring normal kinematics by reducing scapular elevation, anterior tilt and internal rotation (Host, 1995). In a recent study by (Shaheen et al., 2013), taping was found to have no significant effect on SURA in the scapular plane, these findings are consistent with the findings of the present study that tested SURA in the coronal plane.

The results of this study provide evidence for a possible manipulation of the scapular position by using tape, and suggests that Macdonald, (2009) standardization tape application technique that was used in this study facilitates the action of the SA muscle and reduces the upper Trapezius muscle activity. (Morrissey 2000; Macdonald, 2009; Smith et al., 2009) suggests that in order to increase the AHD this may provide a beneficial effect on patients suffering from shoulder impingement and people associated with this condition.

Although there was a positive effect after tape application on the AHD the study however has limitations which were: It was not possible to blind the investigator collecting the data to the taping technique used in order to rule out investigator bias. Only short term effects on SURA and AHD were investigated, further research is required to investigate the long term effects of taping on scapula rotation and AHD. Participants in this study all had healthy shoulders, further research is necessary on participants with SAIS to determine if the results from this study can be extrapolated to this group of patients. The AHD is at its smallest between 60 degrees and 120 degrees of arm abduction (Flatlow et al., 1994). This fact combined with the limitation that visualisation of the AHD in more than 60 degrees arm abduction with US is unreliable, (Desmeules et al., 2004) influenced the choice of testing position. This passive arm position ensured that the participant did not experience fatigue during the testing process. Thus this study did not evaluate the effect of taping in the active arm position nor above 60 of arm abduction.

Another limitation is that possible errors may occur in palpation through numerous layers after applying the tape and the morphological variations and differences in the same subject movements resulted in a different magnitude of change between subjects (Shaheen et al., 20013). However the result provides a good base from which to

further investigate of the effects in people at risk of developing SAIS. Further studies, which take these variables into account and changes in important clinical outcomes, will need to be undertaken.

7.1.6. Conclusion

Returning to the hypothesis posed at the beginning of this study, it is now possible to state that rigid taping techniques increases the AHD in healthy individuals immediately following tape application. There was a significant difference in AHD measured between the three groups of muscles on the effect of tape application. The SURA measured by the PALM showed no significant difference in SURA between the three groups of muscles after the application of the tape. Further studies need to be done to establish whether these changes are clinically important and could improve treatment outcomes in individuals with SAIS.

7.2 The effects of muscle contracting on acromiohumeral distance by using electronic muscle stimulator (NMES).

7.2.1. Introduction

Rehabilitation strategies for people with SAIS frequently address the improvement of neuromuscular control and strength of the scapular muscles (Talbot et al., 2013). In recent years, clinicians have concentrated on re-establishing the normal scapular position and motion to rehabilitate patients with SAIS since the weakness of the scapular musculature will affect the normal scapular positioning and contribute to pain and dysfunction (Cools et al., 2002; Huang et al., 2012).

Electromyographical studies have highlighted muscle activity in subjects with SAIS and healthy individuals (Ludewig and Cook (2000); Cools et al., 2004; Cools et al., 2007; Ackermann et al., 2002) amongst others. For instance; a study by Ludewig and Cook (2000) found that EMG signal amplitude of the Upper Trapezius (UT) is increased, while the Lower Trapezius (LT) and Serratus anterior (SA) are decreased, in patients with shoulder impingement, this resulted in an imbalance between the UT and SA in producing upward scapular rotation (Ludewig et al., 2004). In another study Morin et al. (1997), found a significant decrease in UT and a concomitant significant increase in middle/lower Trapezius EMG signal amplitude with scapular taping compared to no taping, in healthy subjects. Whereas Cools et al (2002) found no significant differences in the surface EMG of the UT and LT and SA muscles between scapular taping and no-taping conditions, during elevation.

Ackermann et al., (2002) evaluated the effects of taping the scapulae of violinists into a position that prevented excessive elevation whilst electromyographic activity was recorded from the UT. The result demonstrated an increase in the left UT muscle

activity during playing in the control condition, however the short-term application of scapula taping did not enhance selected scapula stabilising muscles during playing and was not well accepted by professional violinists.

The Smith, Sparkes, Busse, and Enright, (2009) study observes the imbalance between UT and LT in a symptomatic sample when compared to a separate group of asymptomatic subjects. The authors also examined the effect of commonly used scapular taping technique on the electromyographic activity of UT and LT in the sample population presenting with SAIS. The results found imbalance between UT and LT in the symptomatic sample and a reduction in UT activity in the presence of tape, but no change in LT activity, this identification provides a rationale for attempting to therapeutically alter scapular rotator activity. No relationship was found between the degree of imbalance and the extent of the reduction in UT activity.

Selkowitz et al., 2007 investigated the immediate effects of scapular taping on the surface electromyographic (EMG) signal amplitude of shoulder girdle muscles during upper extremity elevation in individuals with SAIS. The authors indicated scapular taping produced a significant overall decrease in the EMG signal amplitude of the UT with tape compared to no taping during shoulder abduction, and a significant overall increase in LT EMG signal amplitude during the functional task in the scapular plane. The Serratus anterior was not significantly affected by scapular taping. It is possible that this method of taping provides an insufficient indirect influence and these muscles require exercise training to increase their activity in the presence of impingement, no significant interactions were found for other muscles.

Moraes et al., 2008 determined scapular muscle recruitment by the electromyographic activity of the scapular stabilizer muscles (Trapezius and Serratus anterior) and

muscular imbalance in patients with impingement syndrome against healthy individuals. The result illustrated that individuals with impingement syndrome presented significant delays for the recruitment of scapular muscles, showing alterations of dynamic neuromuscular balance. The authors concluded that, assessment of the performance of the scapular stabilizer muscles appears to be more important for the detection of functional deficits in individuals with impingement syndrome, and gives a better guide to therapeutic intervention.

In further studies, Huang et al., 2012 investigated the effect of EMG biofeedback training on muscle balance ratios and scapular kinematics in healthy adults and subjects with SAIS. EMG was used to record the activity of scapular muscles before and after the exercises with/without EMG biofeedback. The result indicated that EMG biofeedback improved the scapular muscular balance during training exercises in both groups. Further clinical trials should investigate the long-term effects of EMG biofeedback.

Overall, previous literature provides evidence supporting the theory that altered scapular rotator activity is present in patients with SAIS and highlights the role of scapular rotator muscle training as an essential component of shoulder rehabilitation (Cools, 2007, 2003). Muscle imbalance as such the high activity of the UT is normally combined with low activity of the LT and the SA in patients with impingement symptoms contributing to abnormal scapular motion. For this reason exercise of the LT and SA activation with minimal activity in the UT are recommended (Cools, 2007).

Clinical practice strategies supported by research data recommended that patients with SAIS presenting primary movement dysfunction of the scapular during arm elevation may use the strengthening program of SA and LT muscles based on biomechanical

considerations, as the Trapezius cannot functionally posteriorly tilt the scapula (Fey et al., 2007, Johnson et al., 1994, Van, 1994). Previous studies have considered the immediate changes in the surface electromyographic activity of the scapular rotators in response to scapular taping; however, no study exists at present on the effect of muscle contracting of the scapular rotators on the AHD.

The application of NMES which is an Neuromuscular Electrical Nerve Stimulation unit is used for various medical applications. It is a commonly employed intervention in rehabilitation and it has been used previously for improving function (Singer, 1987), improving motor control (Glanz, 1996), preventing or reducing shoulder subluxation (Ada and Foongchomcheay, 2002), preventing and treating shoulder pain (de Kroon et al., 2002), increasing range of motion (Quinn and Cramp, 2003), as well as currently it is used in many forms to facilitate changes in muscle action and performance (Doucet et al., 2012). Therefore, this study hypothesises an intervention protocol focusing on the application of NMES in an attempt to address the effect of muscle contracting on the AHD. The rational for using NMES application is to stimulate the scapular muscle.

7.2.1.1 The objective of the study:

- To identify the effect of the lower Trapezius (LT) contraction on AHD.
- To identify the effect of the Serratus anterior (SA) contraction on AHD.
- To identify the effect of combining both lower Trapezius and Serratus anterior (LT & SA) muscles contraction on AHD.

7.2.1.2 Null Hypothesis

- There is no effect of contracting the (LT) muscle on AHD.
- There is no effect of contracting the (SA) muscle on AHD.
- There is no effect of contracting both the (UT&SA) muscles on AHD.

7.2.1.3 Alternative hypothesis

- The effect of the (LT) muscle contraction on AHD will be positive that is the AHD will increase.
- The effect of the (SA) muscle contraction on AHD will be positive that is the AHD will increase.
- The effect of combining both the (UT&SA) muscles contraction on AHD will be positive that is the AHD will increase.

7.2.2 Method and Material

7.2.2.1 Study design

A one-group pre-test/post-test repeated measures design used to compare the effects of muscle contraction on the AHD in healthy individuals.

7.2.2.2 Participants

A power analysis was carried out using G Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), with an effect size of 0.5, a significance level of 0.05, and a statistical power of 0.8, the required sample size was calculated to be 16 participants. The right shoulder of twenty participants (ten males - ten females) with mean age 26.95(\pm 8.03SD) were recruited from the student population of the Health, Sports and Rehabilitation Sciences at Salford University.

Inclusion criteria for the participants was the following: a) no shoulder pain in the previous month prior to participation, b) between 18 and 50 years of age, c) no history

of pain or movement limitation to the shoulder. Exclusion criteria were as follows: Subjects who had any shoulder surgery or clinical treatments for a shoulder injury.

Approval for this study was received from the Institutional Review Board at the host University, in accordance with the latest revision of the Declaration of Helsinki (2008). All participants signed the written informed consent form prior to their participation in this study.

7.1.2.3 Instrument

NMES (Compex Mi Sport DJO International) is a portable unit that stimulates efferent motor neurons with a biphasic waveform (Warren et al., 2011). It replicates the signals of voluntary muscle contractions, working with the muscle fibers instead of the nerve fibers (Doucet, Lam & Griffin 2012). It is a non-invasive technique in which a low-amplitude electrical is delivered through wires to electrodes located on the skin (Robinson, 1996). This is usually used to strengthen and prevent muscle atrophy in a variety of musculoskeletal conditions and it can be used at home or work (Indeck et al., 1975; Roeser et al 1976; Kaada, 1984).

7.2.2.4 Procedure

The participants had contraction sensor surface electrodes place on them, two conductive silicone polymer electrodes were used for stimulation, attached to the NMES machine by a two cord lead, over the skin with electrode pads. The pad is conductive and once checked becomes adhesive allowing the fixation of the electrodes without either jelly or tape. Adjustments to the intensity were made during the session to maintain it at the same acceptable level for the three groups of muscles; group 1: LT muscle, group 2: SA muscle and group 3: combined both muscles LT & SA. All participants received the concentration after an initial examination by the investigator

and they were instructed that the sensation should not be painful, a rest time of 2 min then was allowed prior to the first data collection trial.

NMES allowed 1-10 seconds of contraction, with a fixed three seconds recovery. Ramp time refers to the period of time from when the stimulation is turned on until the actual onset of the desired frequency (Baker et al., 2000), a ramp time of 2 seconds with maximum stimulation muscle contraction lasting for 8 seconds for all participants was used, which should have given sufficient time to take the ultrasound image, the frequency of the output was set at 80 Hz and intensity was raised until the subject reported that it was unpleasant.

7.2.2.4.1 NMES application techniques

All NMES application techniques were done by another investigator who had more than 20 years' experience in musculoskeletal disorders. First, prior to the electrode application the skin of the dominant shoulder was cleaned with alcohol to assist adherence of the NMES. Second, the NMES was applied via sensor surface electrodes placed over the muscle belly of the participants by the investigator according to the protocol described by Basmajian and De Luca (1985).

Group 1: LT muscle: with the participant standing and the electrode positioned over the muscle belly of the LT muscle and it was placed directly upward and laterally along a line between the inferior border of the scapula and the insertion of the muscle on the anterior-lateral side of the seventh thoracic spinous process. The investigator turned the machine on after the electrode was placed. Then, the intensity setting was regulated and was adjusted to the most comfortable intensity level by the investigator and subjects were instructed to indicate when the level of stimulation was at a comfortable level (Fig. 7.2.1).



Figure.7.2.1. Posterior view of the

scapula and electrode placement for the lower trapezius muscle

Regarding the SA muscle the electrode sensors were placed at the intersection of 6th rib and mid axillary line, parallel to the muscle fibres and anterior to the latissimus dorsi muscle fibres.

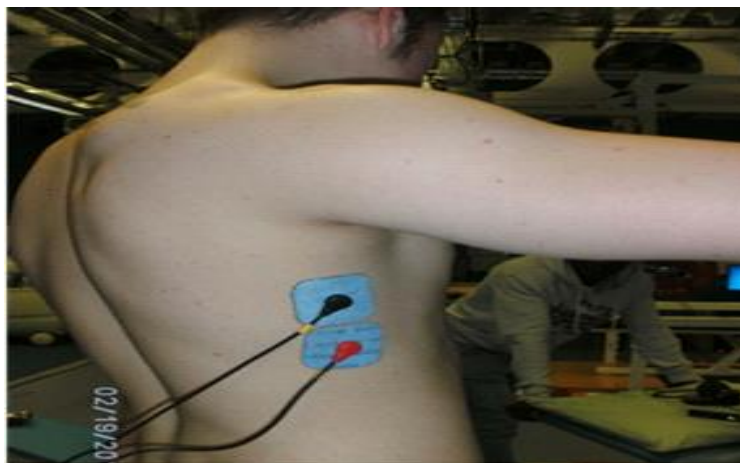


Figure. 7.2.2. Lateral view of the

scapula and electrode placement for the Serratus Anterior muscle (SA).

For the combination of both LT&SA muscles the electrode sensors were placed on both the LT&SA muscles and the same technique that was mentioned above was used by combining both LT and SA muscles together. The same procedure was repeated, electrode sensors were placed at both LT and SA muscles respectively, with the shoulder in neutral (Fig. 7.2.3). In all three groups, after the outcome data were collected, the electrode sensors were removed by the physiotherapist.

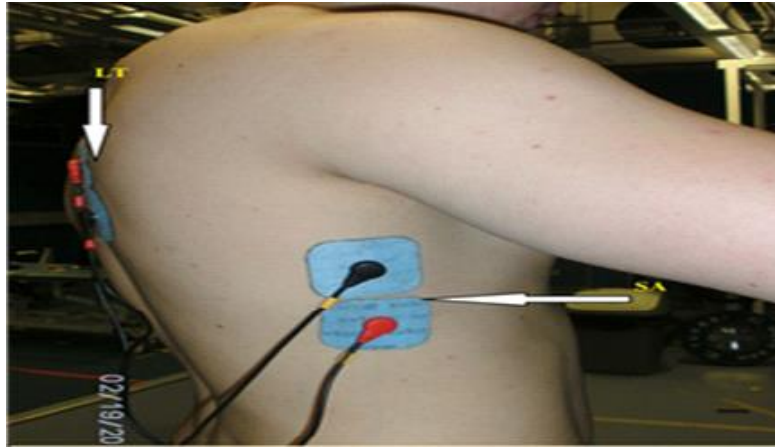


Figure. 7.2.3. Electrode

placement for combination the Lower Trapezius and the Serratus Anterior muscles.

7.2.2.4.2 Ultrasound measurements

The RTUS of the shoulder was performed by a second investigator using Mylab 60 Esaote, Xvisoin model, with a 523 linear transducer and the frequency of the image set at 13 MHz linear transducer. After the NMES electrode were placed over the skin, the second investigator asked the participant to sit with his/her back against the short back rest of the chair, sit up straight, pull their shoulders back and look straight ahead. AHD was measured at 60 degrees of shoulder elevation in the scapular plane. The 60 degrees of elevation was chosen because the AHD is smallest between 60 and 120 (Flatowet al., 1994). A goniometer and wedges were used to ensure the correct position of the arm at 60 degrees of abduction.

The ultrasound transducer was placed on the lateral aspect of the acromion in line with the longitudinal axis of the humerus to visualise both the humerus and the acromion. For images, the AHD was measured vertically, measurements were taken from the lateral edge of the acromion process of the scapula to the nearest margin of the humerus (Girometti et al., 2006), with the arm at 60 degrees of passive abduction position (Fig.7.2.4).

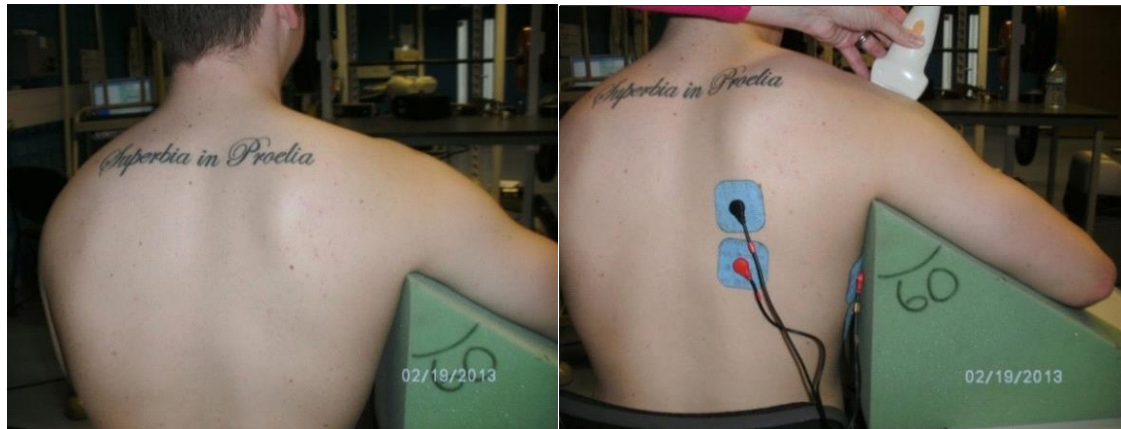


Figure.7.2.4. Posterior view of the placement of electrodes and the standardized position for the measurement of acromiohumeral distance at 60 degrees of abduction by using real time ultrasound scanning before and after NMES application.

Image capture was taken on the same day, ultrasound images were captured at 60 degrees of passive abduction, and measurements were taken on two occasions: Relaxed and during contraction of the effect of muscle stimulation on the AHD in the scapular plane.

All ultrasound images were frozen on the screen and saved onto an external hard drive from the ultrasound scanner and stored for offline analysis using Image J software. A time interval of 5 minutes was provided between each group of muscle measurement. The whole process was repeated 3 times to ensure accuracy and consistency resulting in twelve images per participant for each sitting test condition: LT, SA and combination of both LT with SA muscle groups.

7.2.3 Data analysis

Kolmogorov-Smirnov test was utilised to assess the normality of distribution for testing variables (AHD) before the intervention. Normal distribution was observed for both variables. Within-day reliability and between-day reliability of measuring the AHD was established by calculating the ICC and SEM as discussed in Chapter 4.

Paired t test was used to identify the differences between pre and post ultrasound measurement of AHD for the three groups tested in control and experimental groups and repeated measures ANOVA was used to detect differences between-groups; the data were analysed using SPSS version 20. A p value of <0.05 was considered statistically significant.

7.2.4. Results

This study focused on the AHD measured both for relaxed and during muscle contraction generated by using the NMES unit. This was in order to find the effect of the three groups of muscle contractions on the AHD which were measured when relaxed and contracted by using real time ultrasound scanning.

The AHD increased significantly for the three types of muscle groups after NMES application. No significant difference in the AHD was found between the three groups of muscles after using NMES. All data are presented in Table 7.2.1. This also provides a descriptive data of the mean and standard deviation and the paired t-test.

Table 7.2.1: Paired t-test of acromiohumeral distance measurement for pre/post										
Muscles group	Relaxed				Contracted				t	p-value
	Mean (mm)	SD mm	Min	Max	Mean (mm)	SD mm	Min	Max		
Lower trapezius (LT)	9.76	2.34	5.95	15.32	10.15	2.39	5.99	15.68	-4.63	<.001
Serratus anterior (SA)	9.39	2.31	5.44	15.02	9.99	2.37	5.70	15.94	-5.04	<.001
Combined both muscles (LT&SA)	9.46	2.53	5.45	10.76	10.22	2.35	6.13	16.00	-4.19	<.001

Group 1: The LT muscle group displays an average distance equals to 9.76 mm with (2.34 SD) mm before using NMES, whereas the average distance after muscle contracting by using NMES becomes higher, which is 10.15 mm with (2.39 SD) mm, the increases in the AHD are then found to be highly significant ($t=-4.63$, $p\text{-value}<0.001$) as shown by the t-test (See Figure 7.2.5).

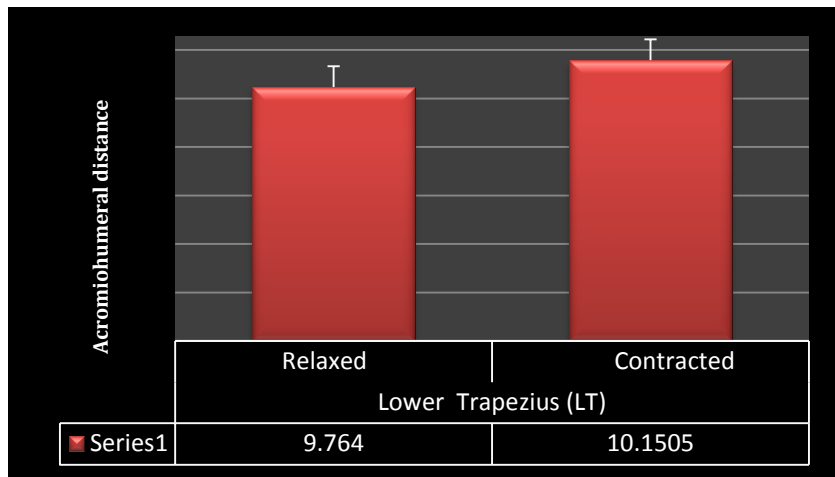


Figure 7.2.5: The effect of Lower Trapezius (LT) muscle contraction by using (NMES) on the acromiohumeral distance.

Group 2: The same scenario is seen for the SA, where the relaxed measure shows an average of 9.39 mm with (2.31 SD) mm, whilst the contracted measure's average indicate 9.99 mm with (2.37 SD) mm, and as a result, the difference is highly significant ($t=-5.04$, $p\text{-value}<0.001$) (See Figure 7.2.6).

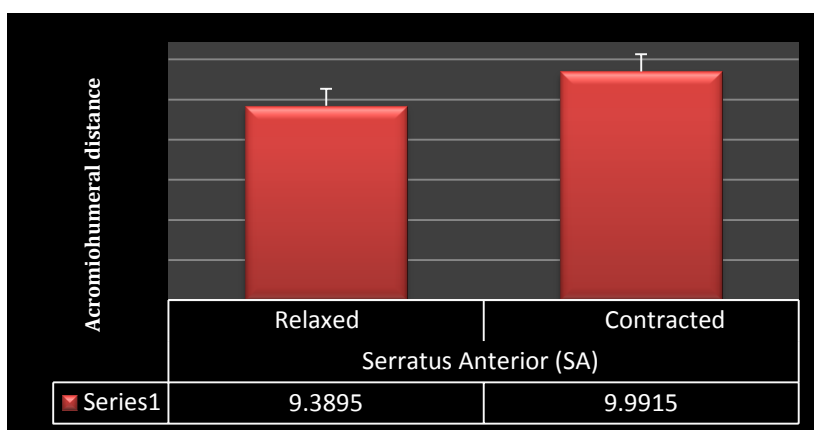


Figure 7.2.6: The effect of Serratus Anterior (SA) muscle contraction by using (NMES) on the acromiohumeral distance.

Correspondingly, for Group 3: combining both groups of muscles LT&SA, the mean of the relaxed measures is 9.46 mm with (2.53 SD) mm, and then it increases to 10.22 mm with (2.35SD) mm after stimulation of both muscles by using NMES, therefore, statistically, the difference in the AHD is highly significant ($t=-4.19$, $p\text{-value}<0.001$) (See Figure 7.2.7).

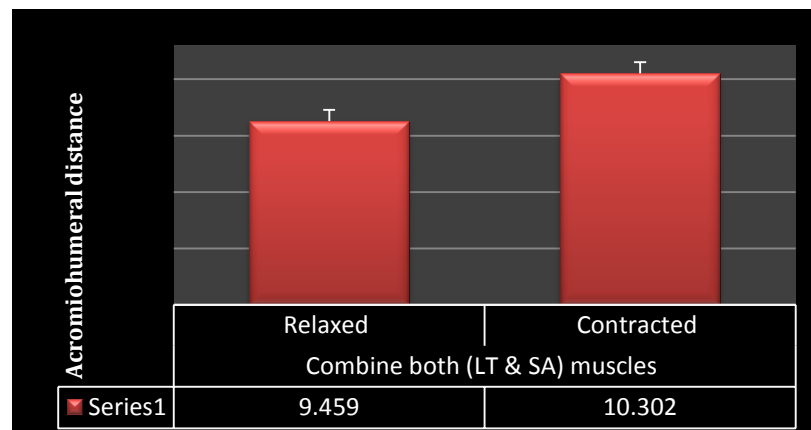


Figure 7.2.7: The effect of combine Lower Trapezius & Serratus Anterior (LT&SA) muscles contracting by using (NMES) on the acromiohumeral distance.

In general, there is significant improvement in the AHD for the three groups of muscles after using the NMES unit. The AHD comparison between the three groups of muscles after using NMES shows, LT with the lowest improvement in AHD after muscle contracting, which is 0.387mm, whereas the AHD shows the highest average, 0.843mm for the LT&SA muscle group, finally the SA group has an average of 0.602mm.

There is a variation noticed between the relaxed and contracted measure for the AHD improvement with each group of muscles therefore, repeated measures ANOVA for the Greenhouse-Geisser was used, which is based on the significant Mauchly's test of sphericity ($\chi^2=11.37$, $p\text{-value}= 0.003$). The differences in the AHD between the three groups of muscles was not statistically significant ($F=3.109$, $p\text{-value}= 0.078$). The differences between the three groups of muscle is shown in Table 7.2.2.

Table 7.2.2: Repeated measures ANOVA using Greenhouse-Geisser

Muscles group	Mean difference between pre/post	F	p-value
Lower trapezius (LT)	.387	3.109	.078
Serratus anterior (SA)	.602		
Combined both muscles (LT&SA)	.843		

Mauchly's Test of Sphericity: chi-square=11.37, p-value=.003.

According to Table 7.2.3, the highest percentage of the increase in the AHD is found to be for the SA muscle group which is 95%, then followed by the LT muscle group with 90%, and finally, for the LT&SA group the AHD improvement is 70%.

Table 7.2.3: Result for the number of participants who showed an improvement in acromiohumeral distance measurement after muscles contracting by using the NMES

Muscles group	Improvement		No improvement	
	Number	%	Number	%
Lower trapezius (LT)	18	90	2	10
Serratus anterior (SA)	19	95	1	5
Combined both muscles (LT&SA)	14	70	6	30

7.2.5. Discussion

The present study was designed to determine the effect of the muscle contracting immediately on the AHD after receiving maximum stimulation by using the NMES unit in asymptomatic individuals. The results showed that the AHD measured by ultrasound, increased significantly after the muscle received the stimulation in all three muscle groups. The results also displayed that there is no significant difference in AHD measurement between the three groups of muscle after receiving the stimulation.

The researcher is unaware of any other investigation about whether muscles contract by using NMES application that could influence the AHD outcome measures. This study is the first to examine the AHD during arm abduction in healthy individuals before and after muscle contracting via NMES. Most of the previous studies have studied the effect of scapular taping on the electromyographic activity of surrounding muscles. However the results between these studies displayed different conclusions; a variable finding has been reported for activation of the LT and the SA, where some studies have found that patients with painful shoulders have less activation of the LT (Cools et al., 2003) and the SA (Lin et al., 2011; Ludewig P, 2000) than in healthy shoulders, whereas others report no differences in the activation of the LT and/or the SA (Cools et al., 2002; Moraes et al., 2008; Selkowitz et al., 2007; Smith et al., 2009).

There is inadequate information in the literature with regard to the effect of muscle activity on the AHD. In a study by Cools, (2007) the authors highlighted that the high activity of the UT is normally combined with low activity of the LT and the SA in patients with impingement symptoms which contributes to abnormal scapular motion; for this reason exercise LT and SA activation with minimal activity in the UT are

recommended. Therefore, the current study takes the causative factors about the functional mechanisms by which muscle needs to be trained in order to increase the AHD.

It was hypothesised that muscle contracting would result in increasing the AHD. Regarding the LT muscle contraction, following the NMES stimulation the AHD increased in 90% of the participants. Similarly, 95% of the participants (which is the highest %) had an increased AHD after stimulation of the SA muscle. For the LT&SA combination there was 70% of participants with an increased distance in AHD.

The findings of the current study partially supported the hypothesis of this study. The AHD increased significantly in all three groups of muscles; LT and the SA and combining both of them after receiving electrode stimulation. However, to ensure that the experimental magnitude change of the AHD attained by the NMES application in this study are sufficient to consider real change, researchers should consider the findings in the light of the methodology reliability of the AHD measurement at 60 degrees abduction which was previously reported in Chapter 4. The method acknowledged it has measurement error (0.24 mm) and (SDD=0.67) which is considered true change.

The magnitude of change for each of LT and SA muscles respectively as observed in the AHD at 60 degrees of abduction is small and it is possible that the difference is a result of a measurement error rather than a real change in AHD. Based on this finding it does not seem that the contraction of either LT or SA separately is important in this study. On the other hand, one of the more significant findings to emerge from this present study is that the magnitude of change in the AHD at 60 degrees of abduction for the combining both muscles LT&SA exceeds both of the measurement method

errors and the SDD; therefore suggesting a real change in AHD that is not attributable to error. One possible explanation for this might be the change caused by combining both LT & SA muscles contracting in the firing pattern of the scapular rotator, which may result in an increase in the AHD. This finding corroborates the ideas of (Ludewig & Cook 2000) who suggested that training the LT and the SA muscles may have an influence on maintaining the AHD by posteriorly tilting the scapula and aiding the scapula in upward rotation. By looking into the effects of muscle contraction on AHD following the NMES stimulation, the results indicated that the immediate effect of NMES stimulation may be considered to be an essential advantage as matched the other physical therapy modalities and can be used by clinicians as an alternative treatment option when an immediate therapeutic effect by shorter application durations is required.

The current investigation is subject to at least three limitations; first, there was no randomisation of the intervention protocol and this may weaken the power of this study. Second, the duration and frequency of the NMES application intervention would affect the results since only short-term effects on AHD were investigated and the NMES contraction lasted for 8 seconds only. Furthermore, the present study does not address the difference in AHD when a participant actively contracts their scapular muscle as oppose to an isolated NMES treatment. Future research studies on the current topic will need to be done to determine the effects of muscle activity on AHD in people with SAIS this would be important to clinicians treating patients with SAIS. More broadly, research is also needed using large randomised controlled trials that could provide more definitive evidence.

7.2.6. Conclusion

The following conclusions can be drawn from the present study; muscle stimulation significantly affects AHD in asymptomatic subjects, although the magnitude of change may be different in the AHD in different muscle groups. Nevertheless an implication of this is the possibility that the use of an NMES application to change muscle movement as a preventive measure in asymptomatic individuals with SAIS pathology is a significant advance. Additional studies are needed to be able to transfer this understanding to symptomatic populations.

Chapter eight

8. Summary, recommendations for future work and conclusions

8.1 Summary

SAIS affects many individuals, but the underlying causes are far from clear. The literature would indicate that changes in AHD appears to be related to SAIS and may be important in the therapeutic treatment and prevention of this disease due to its association with the aetiology of SIS when the arm elevated. AHD seems affected by internal and external factors; the internal factors characteristics by acromion morphology, degree of inflammation in the tendons or bursa of the subacromial space, and the external factors including postural abnormalities, rotator cuff and scapular muscle performance, the scapular and humeral kinematic abnormalities and changes in scapular orientation that can cause dynamic narrowing of the subacromial space. This study examined some of the external factors namely scapular rotation and the distance between the scapular landmark and the spine. From this literature it would appear logical to identify and assess tools which could measure this distance and examine factors which influence this measurement.

This thesis aims to examine one such tool, namely RTUS and its ability to measure AHD, also the PALM to measure SURA, as this has been regarded as a significant factor in influencing this space in the literature.

The specific aims of this thesis were:

1. To establish the reliability of the RTUS to measure the AHD in healthy individuals.
2. To establish the reliability of the PALM to measure the scapular position in healthy individuals.
3. To establish the relationship between the SURA and the AHD.

4. To compare both RTUS measures of the AHD and the PALM measures of the scapular position and rotation to detect differences between patients with SAIS and asymptomatic controls.
5. To investigate the effectiveness of changing the scapular position by taping on the AHD and the SURA.
6. To investigate the effectiveness of muscle stimulation on the AHD by using the NMES.

The work undertaken in this thesis has firstly; established the reliability of the RTUS for AHD test and PALM for scapular position and motion test, as outlined in aims one and two. As such, a reliable method would have multiple uses for rehabilitation or an intervention program for SAIS. For example, the tool could be used in clinical settings and for research; measurement error of the test would enable clinicians to accurately evaluate an individual's performance when evaluating the effect of the intervention. Without the measurement error values, any changes in the performance cannot be exact as it is unknown whether the difference was due to measurement error or a true change in the calculated performance. In conjunction with the ICC, the SEM and SDD with each test was established in order to better understand the result. Understanding the result of the reliability could enable future studies and clinicians to evaluate any changes in individuals and the significant clinical changes can now be found when interventions are studied.

The research then focuses on the correlation between the SURA and the AHD. The results were expected to show how decreases in the SURA would be associated with decreases in the AHD as this variable has the potential to decrease AHD and therefore increase the risk of impingement related injury. The results showed moderate correlations were evident between the AHD and the SURA, suggesting that the SURA

testing in the scapular plane may be useful for observing dyskinesia scapular motion, but does not fully explain why changes in AHD occur.

Regarding aim four, the results detected differences in the SURA and AHD in patients with SAIS compared to asymptomatic controls. They showed that the hypothesis concerning the test sensitivity to detect differences between patients with SAIS and normal data can be confirmed. Patients with SAIS, demonstrate trends of increased narrowing of the AHD when the arm is abducted to 60 degrees compared to healthy controls, this may prove diagnostically useful.

Finally, with regards to aims five and six, a potential chapter was undertaken to determine the effect of the tape application on AHD through the manipulation of the scapular position. The rationale for using taping is to normalise the scapular position by altering the scapular muscle activity and optimising the scapular position; this may provide improvements in the AHD. This chapter also focused on the effect of the muscle stimulation on AHD. The following conclusions can be drawn from this chapter: 1. Rigid taping techniques increase the AHD in healthy individuals immediately following tape application. 2. Muscle contracting affects AHD significantly in asymptomatic subjects.

8.2 Limitations of the work undertaken

Finally, a number of important limitations need to be considered:

1. The measurements for all subjects should be randomised when using the RTUS and PALM to avoid any possible sources of systematic bias.
2. The participants should be from different age groups. In addition, they should display different physical characteristics to increase the generalisability of the resulting dataset.

3. The inter-rater reliability should be assessed for both devices, the RTUS measuring AHD and PALM measuring scapular position and motion.
4. Similar studies should be conducted on patients with subacromial impingement syndrome conditions. This will help clinicians and researchers to use the RTUS and the PALM with more confidence.
5. The factors that may influence AHD, such as dynamic muscle activity were not tested.
6. The limitation in this study which could have affected the measurements was that the numbers of participants with SAIS were relatively small. Likewise, it is noteworthy to realise that the AHD is also affected by other factors such as posterior tilt and external rotation.
7. This study did not evaluate the effect of taping in the active arm position nor above 60 degrees of arm abduction.
8. Another limitation is that possible errors may occur when palpating through numerous layers after applying the tape, and the morphological variations and differences in the same subject movements could have resulted in a different magnitude of change between subjects. However, the result provides a good establishment to further investigations of the effects in people at risk of developing subacromial impingement.
9. There was no randomisation of the intervention protocol and this may weaken the strength of this study. As such, randomised controlled trials are considered to be the most powerful research design for evaluating the effects of interventions in clinical research. Additionally, the randomised trial minimises

the bias that occurs when one group has certain features known or unknown that could affect the outcome of interest (Viera & Bangdiwala, 2007). Consequently, any significant differences between the groups of interest in the outcome can be attributed to the intervention and not to other unknown factors. However, this research established the SEM and SDD values to facilitate clinical interpretation as the measurement error is considered important when evaluating the effect of the intervention, and without it values, any changes in the performance cannot be exactly calculated, as it is unknown whether the difference was due to measurement error or a true change in performance (Munro, 2013). In order for a true change in the performance to be detected, the difference in the scores needs to be greater than the measurement error that relates to the test (Tyson, 2007). Therefore, the smallest detectable difference (SDD) has been obtained to allow the determination of the change needed to indicate statistical significance (Atkinson & Nevill, 1998).

10. The duration and frequency of the NMES application intervention would affect the results since only short-term effects on AHD were investigated and the NMES contraction lasted for 8 seconds only.
11. The present investigation does not address the difference in AHD when a participant actively contracts their scapular muscle as opposed to an isolated NMES treatment.

8.3 Further work

It is recommended that further research be undertaken in the following areas:

Firstly, consideration of the inter-rater reliability of RTUS measurements of AHD distance with large randomised controlled trials would provide more definitive

evidence. Similar studies should be conducted on patients with SAIS conditions. This will help clinicians and researchers to use the RTUS with more confidence. Moreover, this investigator demonstrated a moderate relationship between the SURA and AHD at 60 degrees of passive abduction in healthy participants to confirm these findings and to link scapular kinematics and AHD prior to further clinical decisions based only on theory. However, more research on clients diagnosed with SAIS needs to be undertaken before the association between SURA and AHD is more clearly understood. Nevertheless, investigations associating scapular kinematic alterations to the magnitude of the available AHD and the possible impinging structures are required to further clarify the clinical and biomechanical importance of kinematic alterations in the patient population in other scapular motions, such as dynamic motions, posterior tilt and external rotation that may affect the space. It is suggested that the association of these factors is investigated in future studies.

Further investigation and experimentation of the sensitivity of both RTUS and PALM needs to be carried out using larger sample sizes. The sample size calculation was performed based on the data from a case study and was relatively small. To establish whether these changes are clinically important and could improve treatment outcomes in individuals with SAIS there must be larger samples.

Further research is required to investigate the long term effects of taping on SURA and AHD and the effects of muscle stimulation in order on AHD to change muscle movement as a preventive measure in patients with SAIS pathology.

Future research studies on the current topic will need to be completed to determine the effects of muscle stimulation on AHD in people with SAIS using large randomised controlled trials that could provide more definitive evidence.

More broadly, research is also needed to determine if the results from an intervention program can be extrapolated to a group of participants with SAIS, taking these variables into account and changes in important clinical outcomes, which will all need to be undertaken. Moreover, studies need to be completed to determine the effects of muscle activity on AHD in people with SAIS. This would be important to clinicians treating patients with SAIS.

8.4 General conclusions

The work undertaken in this thesis has expanded the knowledge about the use of RTUS in measuring the AHD and the PALM while measuring the scapular position and motion in healthy individuals. The following conclusions can be drawn from the present thesis: Firstly, the reliability of RTUS was shown to be a reliable device for the measurement of the AHD. This result provided further support for the use of RTUS to measure the AHD, and this imaging technique may help clinicians evaluate intervention strategies to minimise the risks of developing the SAIS categories.

In line with the results of the RTUS reliability, the PALM device was developed to measure SURA this may possibly provide a reliable evaluation of scapular position and motion. Moreover, this research focused on studying the relationship of the scapular rotation on the subacromial space. A moderate correlation between SURA and the AHD measurement was found at 60 degrees of passive abduction and the researcher concludes that researchers should conduct further investigations on

direct associations between scapular kinematics and subacromial space measurements.

The test sensitivity to detect differences between patients with SAIS and normal data to aid in the interpretation of the interventional study results can be confirmed. Patients with SAIS demonstrate trends of increased narrowing of the AHD when the arm is abducted passively to 60 degrees compared to healthy controls. Identification of patients who exhibit SAIS may help to reduce injury occurrence through use of interventions to reduce SAIS.

Studies were also undertaken to assess an intervention programme and evaluate the effect of rigid taping techniques and NMES application on the AHD in healthy individuals. The results of this investigation conclude that there was a significant difference in AHD measured between the three groups of muscles on the effect of tape application. It was also shown that muscle stimulation affected the AHD in asymptomatic subjects significantly, although the magnitude of change may be different in the AHD between different muscle groups. Nevertheless, the results support the hypothesis that the muscle force couple around the scapula is important in rehabilitation and scapula control and has an influence on the AHD. The implication of this is that there is the possibility that the use of an NMES application in order to change muscle movement could be a preventive measure in asymptomatic individuals with SAIS pathology can be established.

Overall, this dissertation has given an account of and the reasons for the widespread use of RTUS and the PALM and explained the central importance of the effect of the scapular position in subacromial space. The results of this series of studies found that a change in the scapular kinematics may lead to SAIS. As a consequence, this change

has the ability to limit the subacromial space and mechanically impinge on the subacromial structure. Moreover, this research provides evidence for a possible mechanism by which tape and NMES may provide benefits for people with SAIS, as one component of a multimodal intervention programme. These findings are important as they start to explain some of the elements which influence AHD, but not all of them. The manipulation of the scapular position either through taping or isometric muscle contraction that influence AHD through their effect on the scapula they give the clinician a potential mode of interaction to influence AHD, but is not likely to be the only intervention which can influence this.

The investigation into the effects of pain from shoulder injuries provided the basis of this research. Shoulder problems present a major social, psychological and economic cost throughout the world and have been claimed as the third most common complaint for clinical appointments. The aim of this study was to establish the reliability of RTUS to measure the AHD and the PALM with which to measure the scapular position in healthy individuals. It can be stated with conviction, that this research study has successfully achieved this. All the evidence of the research has shown RTUS to be a reliable and very useful tool for the medical profession to use to understand more about injuries to shoulders. Therefore, this information can be used to develop targeted interventions aimed at the effects of tape application on AHD through the manipulation of the scapular position and muscle stimulation on AHD in order to provide improvement in the AHD. Thus, a number of possible future studies using the same experimental setup are essential for the benefit of patients and medical personnel.

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Appendix I

Subjective Shoulder Assessment for Healthy Individuals' (chapter 4)



Alya Bdaiwi

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Name

Date

Age **Sex** Male / Female

Which is your dominant hand? Please circle: Right / Left

Have you ever dislocated a shoulder? Yes / No if (Yes) which side Right / Left

Do you ever experiencing clicking/clunking in the shoulder? Yes / No if (Yes)

which side? Please circle: Right / Left / Both

Have you had previous upper limb Surgery? Yes / No if (Yes)

What surgery

And date of surgery.....

Are you pain free at present? Yes / No if (No) give details.....

Present Sport History:

1. What sport do you play at present.....
2. For how many years have you play this sport.....
3. How many hours a week do you play sports that require overhead movements.....
4. How often in a week do you play sports that require overhead movements.....

Past Sport History:

1. What sport have you played in the past.....
2. For how many years did you play this sport.....
3. How many hours a week did you play sports that required overhead movements.....
4. How often in a week did you play sports that require overhead movements.....

Appendix II

Subjective Shoulder Assessment for Patient with Subacromial Impingement Syndrome (chapter 6)

Name

Date

Age

Gender

Female	Male
--------	------

1. Which is your dominant hand?

Right	Left
-------	------

2. Do you currently have or did you experience in the past year:

- Shoulder pain requiring medical attention?

Yes	No
-----	----

- Shoulder pain when you elevate your arm?

Yes	No
-----	----

3. Do you ever have dislocation or subluxation of the shoulder joint?

Yes	No
-----	----

4. Do you suffer from systematic joint diseases or other inflammatory Condition

Yes	No
-----	----

5. Does your shoulder pain interfere with activities of daily living?

Yes	No
-----	----

6. Does your shoulder pain interfere with sporting activities?

Yes	No
-----	----

Appendix III

Academic Audit and Governance Committee

Research Ethics Panel
(REP)

To Alya H Bdaiwi
cc: Dr Lee Herrington, Prof L Funk, Ms S Braid
From Jayne Hunter, Contracts Administrator
Date 16th September 2011



MEMORANDUM

Subject: Approval of your Project by REP
Project Title: The reliability, sensitivity and validity of using real time ultrasound scanning to measure glenohumeral joint function.
REP Reference: REP11/099

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

Jayne Hunter
Contracts Administrator

For enquiries please contact
Jayne Hunter
Contracts Administrator
Contracts Office
Enterprise Division
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Telephone: 0161 295 3530 Facsimile: 0161 295 5494
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Appendix IV



Research, Innovation and Academic
Engagement Ethical Approval Panel

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9 February 2012

Dear Alya,

RE: ETHICS APPLICATION HSCR11/16 - The sensitivity of using real time ultrasound scanning to measure glenohumeral joint function

Following your responses to the Panel's queries, based on the information you provided, I am pleased to inform you that application HSCR11/16 has now been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible.

Yours sincerely,

Rachel Shuttleworth

Rachel Shuttleworth
College Support Officer (R&I)

Appendix V



Research, Innovation and Academic
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18 September 2013

Dear Alya,

RE: ETHICS APPLICATION HSCR13/40 – The influence of changing scapular position on subacromial space using taping and complex electronic muscular stimulator

Based on the information you provided, I am pleased to inform you that application HSCR13/40 has now been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible.

Yours sincerely,

Rachel Shuttleworth

Rachel Shuttleworth
College Support Officer (R&I)

